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(54) **MICROGYROSCOPE WITH INTEGRATED VIBRATORY ELEMENT**

(75) Inventors: **Tony K. Tang**, Glendale, CA (US); **Damien C. Rodger**, Chelmsford, MA (US); **Roman C. Gutierrez**, La Crescenta, CA (US)

(73) Assignee: **California Institute of Technology**, Pasadena, CA (US)

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(52) **U.S. Cl.** **73/504.02**

(58) **Field of Search** 73/504.02, 504.04, 73/504.12, 504.14, 504.15, 514.29, 514.35, 514.16, 514.32

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,002,940 A	*	3/1991	Ogawa	73/505
5,203,208 A	*	4/1993	Bernstein	73/504.12
5,894,090 A	*	4/1999	Tang et al.	73/504.02
6,079,272 A	*	6/2000	Stell et al.	73/504.12
6,164,134 A	*	12/2000	Cargille	73/504.02

* cited by examiner

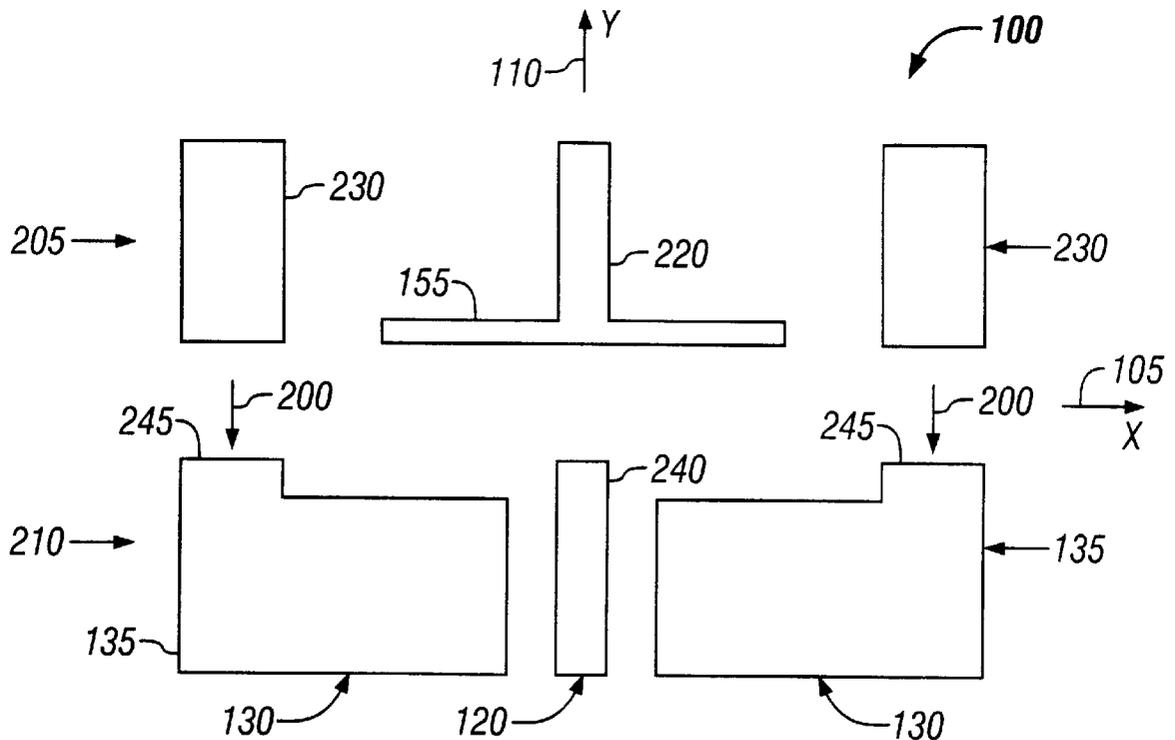
Primary Examiner—Helen Kwok

(74) *Attorney, Agent, or Firm*—Fish & Richardson P.C.

(57) **ABSTRACT**

A microgyroscope having a suspended vertical post uses the Coriolis force to detect the rotation rate. The microgyroscope consists of a single vertical post which is the rotation rate sensing element. The vertical post is formed from the same silicon wafers as the rest of the microgyroscope. A first portion of the vertical post and the clover-leaf structure are made from a first silicon wafer. A second portion of the vertical post and the baseplate are made from a second silicon wafer. The two portions are then bonded together to form the clover-leaf gyroscope with an integrated post structure.

18 Claims, 1 Drawing Sheet



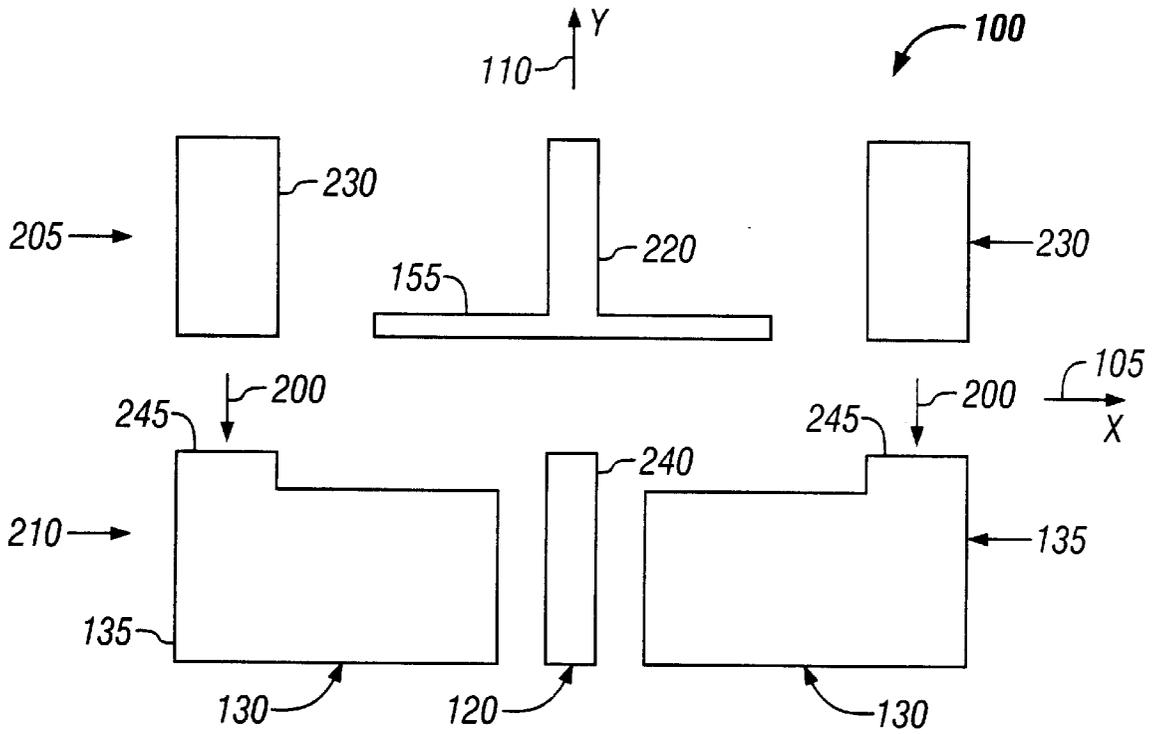


FIG. 1

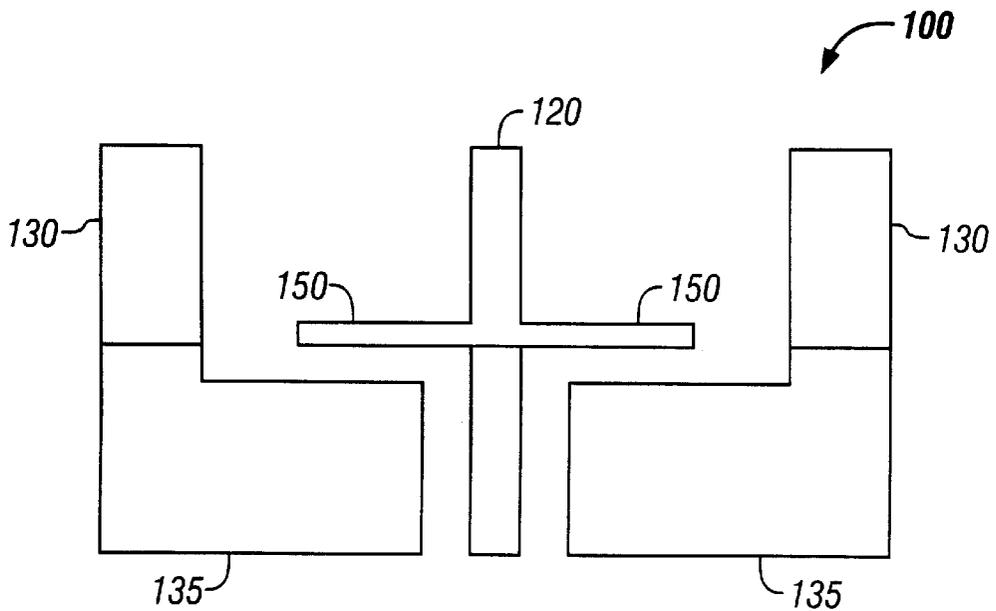


FIG. 2

MICROGYROSCOPE WITH INTEGRATED VIBRATORY ELEMENT

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims benefit of U.S. Provisional Application No. 60/142,850, filed Jul. 8, 1999.

ORIGIN OF INVENTION

The invention described herein was made in the performance of work under a NASA contract, and is subject to the provisions of Public Law 96-517 (35 U.S.C. §202) in which the Contractor has elected to retain title.

TECHNICAL FIELD

This invention relates to vibratory gyroscopes, and more particularly to silicon micromachined vibratory gyroscopes.

BACKGROUND

Multi-axis sensors are highly desirable for inertial sensing of motion in three dimensions. Previously, such sensors were constructed of relatively large and expensive electromagnetic and optical devices. More recently, micromechanical sensors have been fabricated using semiconductor processing techniques. Microelectrical mechanical or "MEMS" systems allow formation of physical features using semiconductor materials and processing techniques. These techniques enable the physical features to have relatively small sizes and be precise. Specifically, micromechanical accelerometers and gyroscopes have been formed from silicon wafers by using photolithographic and etching techniques. Such microfabricated sensors hold the promise of large scale production and therefore low cost.

The integration of three gyroscopic sensors to measure the rotation rates about the three separate axes coupled with three accelerometric sensors to measure the acceleration along the three axes on a single chip would provide a monolithic, six degree-of-freedom inertial measurement system capable of measuring all possible translations and orientations of the chip. There has been some difficulty in constructing a high-performance, or sensitive vibratory rate gyroscope to measure the rotation about the axis normal to the plane of the silicon chip, i.e., the Z-axis.

In a vibratory gyroscope, the Coriolis effect induces energy transfer from the driver input vibratory mode to another mode which is sensed or output during rotation of the gyroscope. Silicon micromachined vibratory gyroscopes are integratable with silicon electronics. These devices are capable of achieving high Q factors, can withstand high g shocks due to their small masses, are insensitive to linear vibration and consume little power. However, most of these micromachined gyroscopes have a very small rotation response, since their input and output vibration modes have different mode shapes and resonant frequencies. The use of different resonant modes also makes these devices very temperature sensitive due to the different temperature dependency of each of the modes. These devices usually have very high resonant frequencies resulting in low responsivity, since the Coriolis induced response is inversely proportional to the resonant frequency of the structure. Finally, due to the small mass of the structure, thermal noise limits the ultimate performance and use of microgyroscopes. For these reasons, micromachined vibratory gyroscopes have not been used for precision navigation and attitude control applications, but have been employed primarily for automotive applications

in which extreme low cost is a major driving factor and performance is set at a lower premium.

Previous microgyroscope designs require manual assembly of the rotation rate sensing element (the vertical post) onto the clover-leaf structure. This process induced asymmetrical stresses in the clover-leaf structure and changes in the mechanical resonant frequencies and model shapes. These changes in the mechanical resonant frequencies and model shapes result in performance variations from device to device under either constant or varying temperature conditions.

SUMMARY

The present invention is a microgyroscope which uses the Coriolis force to detect the rotation rate. The microgyroscope consists of a single vertical post which is the rotation rate sensing element. The vertical post is formed from the same silicon wafers as the rest of the microgyroscope. A first portion of the vertical post and the clover-leaf structure are made from a first silicon wafer. A second portion of the vertical post and the baseplate are made from a second silicon wafer. The two portions are then bonded together to form the clover-leaf gyroscope with an integrated post structure.

DESCRIPTION OF DRAWINGS

These and other features and advantages of the invention will become more apparent upon reading the following detailed description and upon reference to the accompanying drawings.

FIG. 1 is a side view of the components of a microgyroscope constructed according to one embodiment of the present invention.

FIG. 2 is a side view of the bonded microgyroscope according to one embodiment of the present invention.

DETAILED DESCRIPTION

FIG. 1 is a side view of a microgyroscope **100** constructed according to one embodiment of the present invention. The microgyroscope **100** detects forces in the x-direction **105**, the y-direction **110**, and in the z-direction. Vertical capacitors **130** surround the vertical post **120**. The vertical capacitors **130** provide electrostatic actuation-of the vertical post **120** and allow for capacitive detection of the motions of the vertical post **120**.

A first section **205** of the microgyroscope **100** is made from a first silicon wafer and a second section **210** of the microgyroscope is made from a second silicon wafer. The first section **205** of the microgyroscope **100** includes a first portion **220** of the vertical post **120** including flanges **155** and first portions **230** of the vertical capacitors **130**. The second section **210** of the microgyroscope **100** includes a second portion **240** of the vertical post **120**, second portions **245** of the vertical capacitors **130**, and a baseplate **135**. Although the invention is described with the vertical capacitors **130** being constructed of first portions **230** and second portions **245**, it can be appreciated that the first portions **230** and second portions **245** may be electrically isolated to create even more independent vertical capacitors **130**.

To construct the microgyroscope **100**, the first section **205** is positioned above the section **210**. The first section **205** is lowered as indicated by reference numeral **200** onto the second section **210**. The first and second sections **205**, **210** are then bonded together using standard bonding techniques such as-metal-to-metal bonding. The first and second sec-

tions **205, 210** are bonded in a position so that the first portion **220** and the second portion **240** of the vertical post **120** are aligned to form one continuous vertical post **120**. The first portions **230** of the vertical capacitors **130** are aligned with the second portions **245** of the vertical capacitors **130** on the baseplate **135**. Of course, the first portions **235** and the second portions **230** may be electrically isolated. Thus, once the first section **205** is connected to the second section **210**, the vertical post **120** is positioned with the microgyroscope **100**.

FIG. 2 shows a side view of the completed microgyroscope **100** according to one embodiment of the present invention. Once constructed, the vertical post **120** is supported by a series of flanges **150**. The flanges **150** allow the vertical post **120** to rest upon the baseplate. As can be seen in FIG. 2, the flanges **150** are positioned at approximately the mid-point of the vertical post **120**. Because the vertical post **120** is connected to the baseplate **135** via the flanges **150** at approximately the mid-point, the vertical post **120** is free to move in a rocking motion in the x-direction **105** and the y-direction **110**. Under input rotation, the Coriolis force causes the vertical post **120** to move in the orthogonal direction to the drive motor. The rotation rate sensitivity is proportional to the input rotation rate, the drive amplitude, and the quality factor of the resonator.

Because each portion of the microgyroscope **100** is constructed from a silicon wafer, the performance variations from device to device is reduced. Further, the behavior of each portion of the microgyroscope **100** under varying temperature conditions is more consistent.

Numerous variations and modifications of the invention will become readily apparent to those skilled in the art. Accordingly, the invention may be embodied in other specific forms without departing from its spirit or essential characteristics.

What is claimed is:

1. A microgyroscope comprising:
 - a first portion of a vertical post and a clover leaf structure formed from a first silicon wafer; and
 - a second portion of the vertical post and a baseplate formed from a second silicon wafer; wherein the first portion of the vertical post and the clover leaf structure are bonded to the second portion of the vertical post and the baseplate.
2. The microgyroscope of claim 1, wherein the clover-leaf structure includes a plurality of capacitors positioned proximate the vertical post.
3. The microgyroscope of claim 2, wherein the plurality of capacitors provide an excitation force for the vertical post.

4. The microgyroscope of claim 1, wherein the vertical post is free to move in a z-axis.

5. The microgyroscope of claim 1, wherein the microgyroscope is bonded at approximately a mid-portion of the vertical post.

6. The microgyroscope of claim 1, wherein the bond is a metal-to-metal bonding.

7. A method of constructing a microgyroscope comprising:

10 forming a first section of the microgyroscope having a first portion of a vertical post and a clover-leaf structure on a first substrate;

forming a second section of the microgyroscope having a second portion of the vertical post and a baseplate on a second substrate; and

15 bonding the first section of the microgyroscope to the second section of the microgyroscope.

8. The method of claim 7, further comprising forming a single vertical post from the first portion and the second portion.

9. The method of claim 7, wherein the first substrate and the second substrate have similar thermal properties.

10. The method of claim 7, wherein the vertical post is free to move in a z-axis.

11. The method of claim 7, further comprising forming support flanges on the first portion of the vertical post.

12. The method of claim 7, wherein the bonding is a metal-to-metal bonding.

13. A method of constructing a microgyroscope comprising:

30 forming a first portion of a post and a first plurality of capacitors on a first substrate;

forming a second portion of the post and a baseplate on a second substrate; and

35 bonding the first portion of the post and the first plurality of capacitors to the second portion of the post and the baseplate.

14. The method of claim 13, further comprising creating the bonding at approximately a mid-point of the microgyroscope.

15. The method of claim 13, further comprising positioning the plurality of capacitors proximate the post.

16. The method of claim 13, wherein the plurality of capacitors form a clover-leaf structure.

17. The method of claim 13, further comprising forming support flanges on the first portion of the post.

18. The method of claim 13, wherein the bonding is a metal-to-metal bonding.

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