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Electrostatically Levitated Ring-Shaped Rotational-Gyro/Accelerometer

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1. Introduction

Various applications such as advanced automotive safety systems, virtual reality and robotics increase the demand for low cost angular rate sensors with high accuracy. One solution fulfilling these requirements is a MEMS sensor. The most common miniaturized gyroscopes are vibratory gyroscopes, which detect Coriolis force. Although a rotational gyroscope has the ability to obtain high resolution, it has hardly been researched in MEMS.

The aim of our project is the development of an electrostatically levitated rotational-gyro/accelerometer fabricated by MEMS technology [1]-[3]. Due to the levitation of the rotor and an operation in a vacuum, the micro levitated gyroscope can eliminate a mechanical friction and yield high sensitivity. The previous type of the device was reported in 2001[3]. However, levitation control for radial axes requires high voltage. A new ring-shaped micro gyro/accelerometer has radial stators with narrow gap formed by deep RIE (reactive ion etching) and lower voltage generates a levitation force in radial directions.

The levitated rotational-gyro/accelerometer consists of a spinning rotor and stators that maintain the rotor at its null position by a levitation control [3], [5]. The rotation of the micro gyroscope is operated with a principle based on a planer variable capacitance motor [3], [5]. When an angular rate orthogonal to the spinning axis is applied, a precession torque returns the rotor to the null position by the levitation control. The input rate is determined by detecting the magnitude of the torque and the axis of the late is orthogonal to the axis of the torque. Thus, the device works as a dual-axes gyroscope. Additionally, the position control for the levitation allows the device to act as a force-balanced tri-axis accelerometer. In this way, the device realizes an inertial measurement sensor with five degree-of-freedom.

In this paper, we present new design of a levitated micro rotational gyro/accelerometer (multi-axis inertia sensor) and experimental results.

2. Sensor Geometry

The levitation control of the rotor is achieved by using capacitive detection and electrostatic actuation. Stator electrodes are symmetrically arranged around the rotor and forms capacitance gap. Fig.1 depicts the schematic view of the device. The device consists of a glass/silicon/glass triple stack structure. Silicon layer forms a ring-shaped rotor, electrodes for radial position control and common electrodes for output. Radial gaps between the rotor and electrodes are formed by deep RIE. The rotor has a diameter of 4mm, 300μm wide, 150μm thick and a radial gap of 5μm. Electrodes for axial position control, rotation control and common electrodes are placed on top and bottom glass plates and 1.5μm axial gaps are formed.

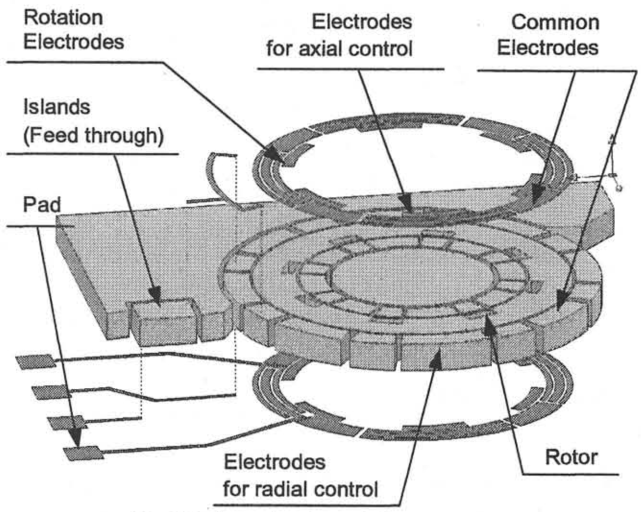

Fig.1 Schematic view of the gyroscope

3. Fabrication Process

The fabrication sequence of the device consists of the following simple processing steps: (shown in Fig.2)

First, Pyrex glass wafers are patterned and etched by HF to define capacitance gaps for axial control and stoppers. Subsequently metal layers are deposited and patterned to provide the electrodes and electrode pads (1). A top glass is anodically bonded with a silicon wafer (150μm thick) (2). The silicon wafer is then etched by deep RIE to release the rotor and islands for feed through, and capacitance gap for radial control is formed simultaneously (3). The stacked wafer is then bonded to a bottom glass, which forms a cavity to encapsulate the rotor (4). Finally, the wafer is diced (5).

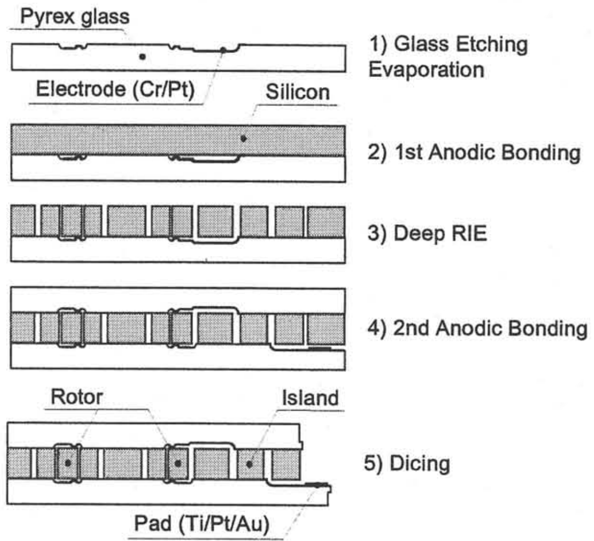

Fig.2 Process chart

4. Performance Measurement

The performance of the device has been tested using a rollover setup with a reference gyroscope. The device was characterized in a vacuum chamber. The rotational speed of the rotor was maintained to 10000rpm. Fig.2 shows the waveform of output from the device. The characteristic of multi-axis accelerometer has been tested using tilt stage. The result is shown in Fig.3. The sensitivity of the feedback voltage was 0.80V/G to axial acceleration, 5.76V/G to radial acceleration and 6.5mV/(deg/sec) to angular late. The measured noise floor of gyroscope output was about 0.15deg/hour$^{1/2}$ and these of the accelerometer output were 30μG/Hz$^{1/2}$ in axial axis and 20μG/Hz$^{1/2}$ in radial axes. Table I summarized characteristics of the device.

Table I Characteristics of the rotational-gyro/accelerometer

Parameters	
Ring diameter (mm) capacitance gap (μm)	*F4mm×150μm(H)×300μm(W) *2.5μm (axial) / *5μm (radial)
Dynamic range (gyro) (accelerometer)	*400deg/s *2.5G (axial)/*2G (radial)
Sensitivity (gyro) (accelerometer)	6.5mV/(deg/sec) 0.80V/G (axial) / 5.76V/G(radial)
Resolution (gyro) (accelerometer)	0.15 deg/hour$^{1/2}$ 30μG/Hz$^{1/2}$ (axial) 20μG/Hz$^{1/2}$(radial)
Servo freq. (kHz)	1kHz (x,y-axis) / 2kHz (z,θ,ϕ-axis)

*designed

5. Conclusion

A new electrostatically levitated rotational gyroscope was designed, fabricated and tested. Characteristics of tri-axis accelerometer and dual-axis angular rate sensor have been obtained. Performance measurements show that it has high resolution and low output noise. Some performance specifications are listed in Table I.

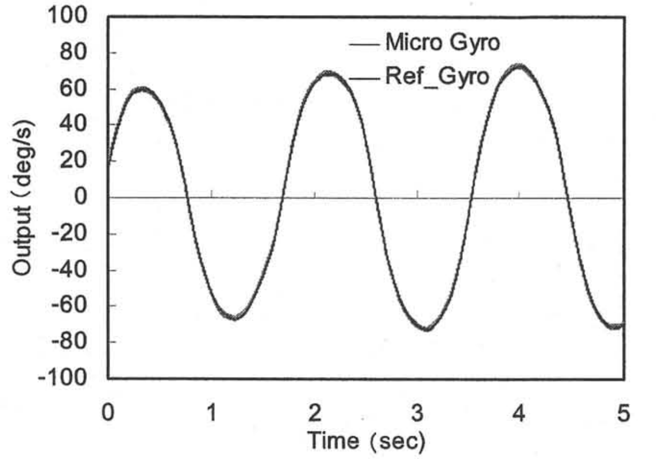

Fig. 2 The measured gyroscope response

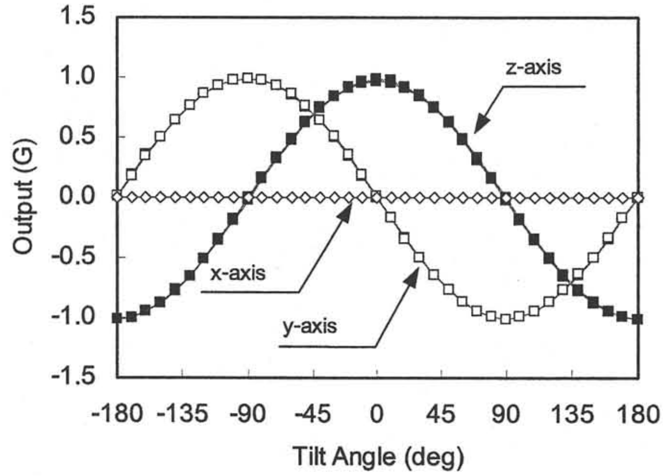

Fig.3 Characteristics of multi-axis accelerometer

Acknowledgements

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