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대기압형 단결정 실리콘 MEMS 각속도계의 설계, 제작 및 성능 측정

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Design, Fabrication and Performance Test of A Non-Vacuum Packaged Single Crystalline Silicon MEMS Gyroscope

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Abstract - In this paper, a non-vacuum packaged single crystalline silicon MEMS gyroscope is designed, fabricated and tested. To reduce air damping of the gyroscope structure for non-vacuum packaging, air damping model is used and damping is minimized by analysis. The inner and outer spring length is optimized by ANSYS simulation for rigid body motion. The gyroscope is fabricated by SiOG(Silicon On Glass) process. The performance of the gyroscope is measured to evaluate the characteristic of the gyroscope. The sensitivity, non-linearity, noise density and the bias stability are measured to 9.7693 mV/deg/s, 04265 %, 2.3 mdeg/s/rtHz and 16.1014 deg/s, respectively.

1. INTRODUCTION

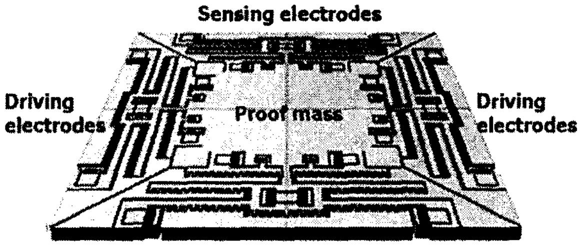
Gyroscopes are devices that transduce an angular rate into a measurable signal, such as a linearly scaled current or voltage output with a given sensitivity. A number of vibratory gyroscopes have been demonstrated, including tuning forks gyroscope, vibrating beams, and vibrating shells in MEMS technology[1]. Recently, silicon vibratory gyroscope has been intensively studied by many research groups, because of well developed silicon micromachining technologies. And a vacuum packaging technology is also a focused area in silicon gyroscope research. As the performance of gyroscope is strongly related to the Q-factor of gyroscope structure, many research groups have been developed vacuum packaging technologies to increase Q-factor of the structure. However, the yield, the life time and the cost of vacuum packaging are not good for commercialization. And it is known that the cost of MEMS packaging consists 70 % of the cost of MEMS device[2].

Therefore, the non-vacuum packaged single crystalline silicon MEMS gyroscope is presented in this paper. The proposed design is based on z-axis vibratory gyroscope and the gyroscope is driven electrostatically and sensed capacitively. And in order to reduce the air damping for non-vacuum packaging, low damping design concept is adopted in this paper.

2. DESIGN OF GYROSCOPE

2.1 Gyroscope structure

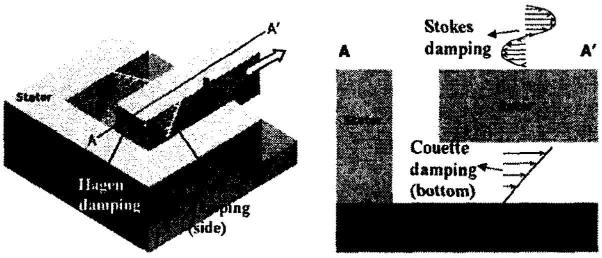
The proposed gyroscope is roughly divided into proof mass, driving part, and sensing part, as shown in figure 1. The driving force is generated in the driving part, and the energy is transferred to the sensing part through the proof mass by Coriolis force. The comb fingers in driving part are used to convert the input voltage to the driving force, and the comb fingers in sensing part are used to convert the displacement of the electrode to the change of capacitance. Generally, the comb electrode is used in driving part and the parallel plate electrode is used in sensing part in MEMS vibratory gyroscope, as the comb electrode has a good linearity and the parallel plate electrode has a good sensitivity. However, to implement the non-vacuum packaged gyroscope, the parallel plate electrodes can not be used, because air damping generated by parallel plate is large. Therefore, the gyroscope has symmetric comb finger structures, in order to obtain a low air damping coefficient. But the sensitivity of the comb fingers is small, compared to the parallel plate electrodes. Therefore, it is needed to increase the sensitivity of the sensing electrode, In the proposed gyroscope, the comb electrodes are arranged like a set of stairs to increase the sensitivity of the sensing electrodes, as shown in figure 1. And the driving force of the gyroscope is also increased, as the gyroscope has a symmetric structure.



<Figure 1> Schematic of the proposed gyroscope

2.2 Low damping design

In order to develop the non-vacuum packaged gyroscope, the low damping structure is essentially needed. The air damping model is used and minimized in the proposed gyroscope. In figure 2, the air damping at the sides of electrodes and air damping at the bottom of moving part is illustrated[3].



(a)Damping at the sides of electrode (b)Damping at the bottom of moving part

<Figure 2> Damping modeling

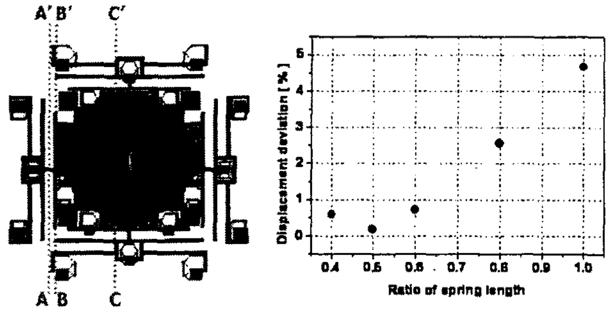
To reduce air damping in the gyroscope structure, the device has lateral-moving and high-aspect-ratio comb fingers for driving and sensing electrodes, and has a large gap between the comb fingers and also between a substrate and the structure.

2.3 Spring design

In the proposed gyroscope, the comb electrodes are arranged like a set of stairs to increase the sensitivity of comb fingers in sensing part. However, there is a problem of a different phase between the inner and outer part. To keep the rigid body motion between the inner and outer part of the gyroscope, the stiffness of the inner and outer spring is optimized by ANSYS analysis.

In figure 3 (a), the first modal result of gyroscope is shown and three paths are shown. The ratio inner and outer spring length are changed from 0.4 to 1.0 in the simulation. And the nodal data is acquired along the three paths (A-A', B-B', C-C'). The figure 3 (b) shows the relation between the ratio of spring length and the standard deviation divided by average of displacement of each nodal displacement. The displacement deviation is minimum, when the ratio of spring length is 0.5. Therefore, the ratio of spring length between the inner and outer spring is set to

0.5 in the gyroscope.



(a) First modal result and selected nodes along three path (b) Ratio of spring length vs. displacement deviation

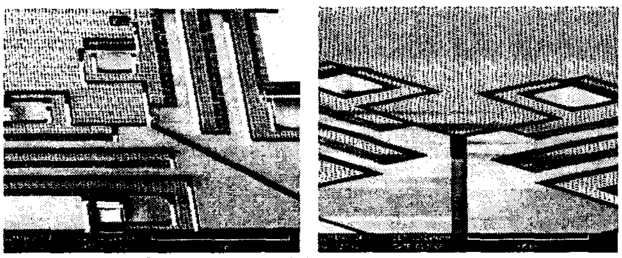
<Figure 3> ANSYS simulation results for spring optimization

3. FABRICATION AND TEST OF GYROSCOPE

3.1 Fabrication

The proposed gyroscope is fabricated by a single mask process[4], which uses a silicon-glass anodic bonded wafer. Because the gyroscope structure has only one structure layer, the fabrication process of the device is simple. The process begins with an anodic bonding of a single crystalline silicon wafer and a pyrex #7740 glass wafer. The bonded wafer is chemically etched in KOH solution and is polished by a chemical mechanical polishing(CMP) process to obtain the 50 μm thick device. The process is followed by silicon dioxide deposition on the silicon surface as a deep RIE etching mask. Then, the pattern of the accelerometer is defined on the silicon dioxide surface by a photolithography process. And the single crystalline silicon is etched by deep RIE process. The structure is released by glass etching in HF solution. The process is followed by a Cr/Au evaporation on the silicon surface for the formation of electrode. Finally, the wire bonding process with PCB is performed.

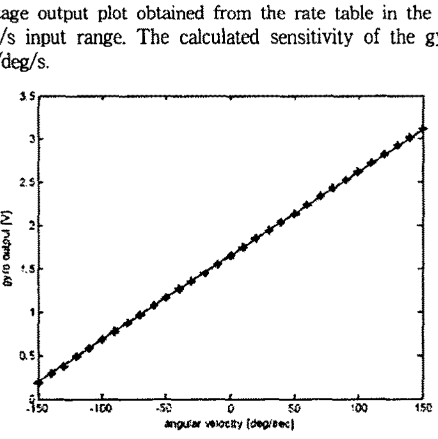
It is shown that The SEM image of the fabricated gyroscope in figure 4. The size of fabricated device is 9920 μm × 9920 μm. And the symmetric structure is shown in figure 4.



<Figure 4> SEM image of fabricated gyroscope structure

3.2 Performance Test

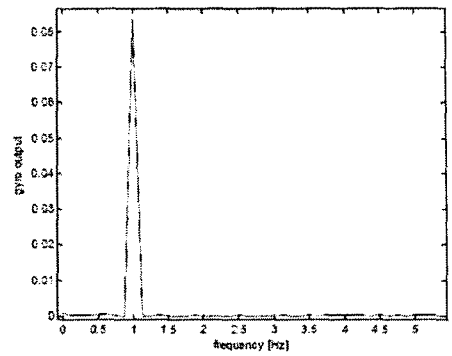
The performance of the gyroscope is measured. In previous researches, the completed gyroscope needed to be tested and calibrated after vacuum packaging. However due to the non-vacuum operation of the proposed gyroscope, it becomes possible to do this testing rapidly without vacuum packaging or vacuum chamber. Figure 5 shows the angular rate input versus voltage output plot obtained from the rate table in the -150 deg/s to 150 deg/s input range. The calculated sensitivity of the gyroscope is 9.7693 mV/deg/s.



< Figure 5> Angular velocity versus gyroscope output

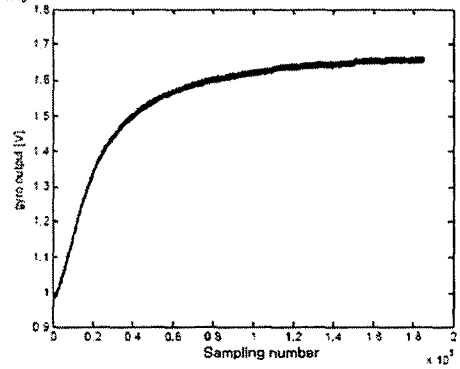
The curve fitted line of the gyroscope input versus output is shown in figure 5. And the non-linearity of the gyroscope is calculated from the results. The non-linearity of the gyroscope is 0.4265 %.

Figure 6 shows the output response of the gyroscope at 10 deg/s, 1 Hz sine wave rate input. The noise density is calculated to 0.0023 deg/s/rtHz.



<Figure 6> Measured noise density

The bias stability is an output when no angular velocity is applied. The bias stability is calculated form turn-on time of the system. From the turn-on time, we obtain the output of the gyroscope when no angular velocity is applied. And the value of the bias stability is obtained by calculating the standard deviation of the sensor output for 60 minutes. Figure 7 shows the bias drift of the fabricated gyroscope. The bias stability of the gyroscope is calculated to the 16.1014 deg/s. From the figure 7, it is considered that the bias of the gyroscope is influenced with the temperature at the near of the turn-on time. Therefore, the temperature compensation circuit will be added for good characteristic of bias stability



<Figure 7> Measured bias drift of gyroscope

4. CONCLUSION

This paper presents the non-vacuum packaged single crystalline silicon MEMS gyroscope. The symmetric comb electrode structure of the driving and sensing part is used to lower the air damping coefficient for non-vacuum packaging. And the inner and outer spring is optimized for rigid body motion of sturcutre by ANSYS simulation. The performance of the gyroscope is measured and the sensitivity, non-linearity, noise density and the bias stability are measured to 9.7693 mV/deg/s, 04265 %, 2.3 mdeg/s/rtHz and 16.1014 deg/s, respectively. To improve the bias stability of the device, the temperature compensation is needed. As the proposed gyroscope has no need of vacuum packaging, this concept of the gyroscope is suitable to the mass production.

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