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MEMS공진형 자이로스코프 응용을 위한 다중질량시스템에 관한 연구

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A study on Multi Mass System for MEMS vibratory Gyroscope

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Abstract - In this paper, a two-mass system for SiOG (Silicon on Glass) vibratory gyroscope with the need of frequency tuning was proposed to increase the stability of the device with wide bandwidth. Air damping and bandwidth were analyzed using MATLAB. The measured resonance frequency is 5.2 kHz, which is 7 kHz in the design. But the measured bandwidth is 450 Hz, similar to the designed bandwidth with 500 Hz. Also the frequency difference (210 Hz) between the driving and sensing part is smaller than the wide bandwidth of two mass system.

1. INTRODUCTION

Gyroscopes are important devices in automotive, aviation and military applications. Gyroscopes and inertial measurement devices are produced cheaply with the development of MEMS (Micro Electro Mechanical System) [1-3]. Recently, the single crystalline silicon gyroscopes were intensively researched for high sensitivity, high resolution and simple process which is based on Silicon on Glass (SiOG) process [4]. In a single mass system that is conventionally used for vibratory gyroscopes, the resonant frequencies of driving and sensing part are designed and tuned to match frequencies in order to achieve high sensitivity. Also, the gyroscope is operated at the peak of the response curve [5]. Since it is difficult to reduce the fabrication error and environmental effect, the variation of the frequency characteristics is not controllable, and fabrication yield and productivity are affected by unwanted variations.

Cenk Acar proposed four DOF (Degree of freedom) micro-machined gyroscopes for surface micro-machining process theoretically to reduce the fabrication error and environmental effect, the variation of the frequency characteristics [6]. This gyroscope has both two mass system driving part and sensing part.

In this paper, we design, fabricate and measure the 3-DOF two-mass vibratory gyroscope having large thickness (80 ㎛) using SiOG process with wide bandwidth for performance stability of fabrication error.

2. THEORY OF TWO-MASS SYSTEM

The two-mass system of the gyroscope can be modeled as a two degree of freedom mass-spring-damp system, as shown in Figure 1. Assuming linear springs and damping, the basic equations of motion of the two-mass system are given by

$$m_1 \ddot{x}_1 + c_1 \dot{x}_1 - c_1 \dot{x}_2 + (k_1 + k_2)x_1 - k_2 x_2 = F\cos\omega t \quad (1)$$

$$-k_2 x_1 + m_2 \ddot{x}_2 + c_2 \dot{x}_2 + k_2 x_2 = 0 \quad (2)$$

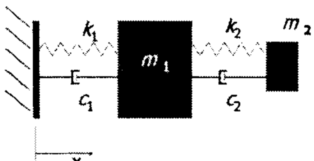


Figure 1. *The model of the two-mass system gyroscope*

3. DESIGN

The proposed design is based on the application of dynamic amplification into the 2 DOF driving direction resonators which is structurally separated to achieve large oscillation amplitudes without resonance.

Figure 2 shows comparison of frequency between single mass system and two-mass system. The two-mass system gyroscope is operating in the flat region. Therefore, the vibration in resonant frequency doesn't affect the characteristics of the gyroscope. The gyroscope is composed of frame mass, proof mass and driving mass. The driving mass is operated by electrostatic force of comb type actuators and transfers the electrostatic force to the frame mass. Figure 3 shows schematics of the two mass system gyroscope. In this design, the natural frequency is 7001 Hz, and chip size is 10 mm×10 mm. To improve sensitivity, sensing electrodes are implemented by parallel plate.

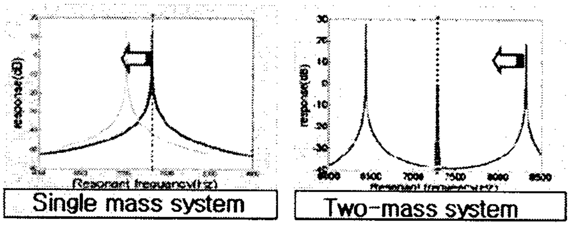


Figure 2 *Frequency comparison between single mass system and two-mass system*

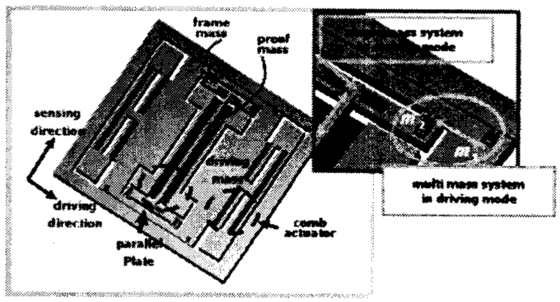


Figure 3. *The schematics of the two-mass system gyroscope*

4. ANALYSIS

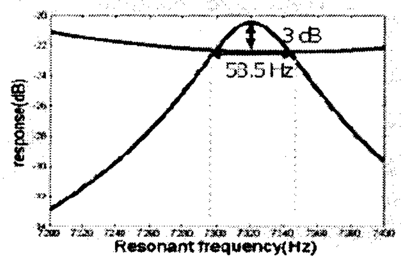
The characteristics of the two-mass system gyroscope are analyzed using MATLAB.

Figure 4 shows bandwidth comparison of result signal mass and two-mass systems in the same displacement. In the 7 kHz resonant frequency designed, bandwidth is 395.3 Hz in the two-mass system's, which is six times larger than single mass system's bandwidth, 58.5 Hz. Therefore the proposed two mass system gyroscope can solves mode matching problem easily.

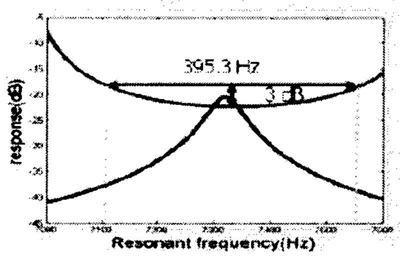
5. FABRICATION AND EXPERIMENTAL RESULTS

The MEMS vibratory gyroscope is designed and fabricated with the two-mass system driving part. The size is 10 mm × 10 mm and fabrication process is based on SiOG (Silicon on Glass)[6]. The fabrication structure's thickness is 80 μm except for the glass's thickness.

Figure 5 shows the fabricated device and figure 6 shows spring width. The spring width decreased from 4 μm to 3.4 ~ 3.6 μm. Figure 7(a) shows comparison of resonance frequency. The measured frequency is decreased from 7000 Hz to 5200 Hz in atmospheric condition, caused by reduction of the spring width. The measured bandwidth, 450 Hz is deviated 10 % from the designed value, 500 Hz. Figure 7(b) shows change of frequency response between expected and measured value. Difference of frequency response is 210 Hz, but this system is able to measure. Because difference of frequency between the driving and sensing part is smaller than the bandwidth.



(a)



(b)

Figure 4. *Bandwidth comparison results of single mass and two-mass system: (a) the single mass system's bandwidth (b) the two-mass system's bandwidth*

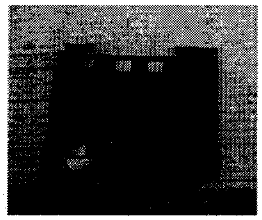
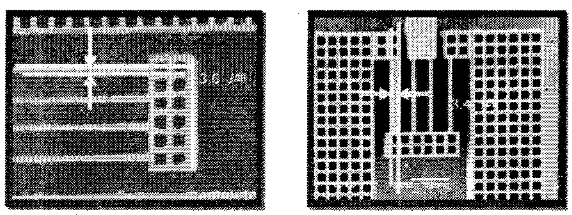
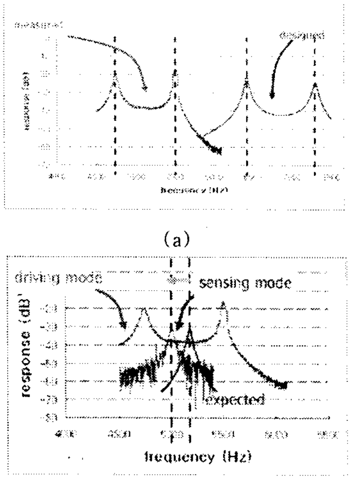


Figure 5. *The fabricated device*



(a) (b)

Figure 6. *Fabricated spring (a) sensing part (b) driving part*



(a)

(b)

Figure 7. *(a) Comparison resonance frequency of deriving mode between designed and measured (b) Frequency response*

6. CONCLUSION

This paper describes a two-mass system for SiOG(Silicon on Glass) vibratory gyroscope so as to increase the stability of the device with wide bandwidth. The gyroscope having wide bandwidth was designed utilizing the two-mass system in order to reduce the degradation of the performance by resonance variation. The two-mass system gyroscope is operating in the flat region. Therefore Therefore, the vibration in resonant frequency doesn't affect the characteristics of the gyroscope. The two-mass system of 7 kHz resonant frequency has 395.3 Hz bandwidth in MATLAB analysis,, which is six times larger than single mass system's bandwidth 58.5 Hz. After fabrication, the spring width is decreased from 4 ㎛ to 3.4 ~ 3.6 ㎛ and measured frequency is decreased from 7,000 Hz to 5,200 Hz. Also frequency difference between the driving and sensing part (210 Hz) is smaller than the wide bandwidth. Therefore, the proposed two-mass system gyroscope has robust characteristics against resonance frequency variation. In this study, the proposed two-mass system can complement the frequency characteristics with wide bandwidth. Thus, the two-mass system can improve the fabrication yield and productivity.

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