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SiOG 기판을 이용한 초소형 가속도계의 설계 및 제작

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Design and fabrication of micromachined accelerometer using SiOG substrate

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Abstract - This paper presents design and fabrication of micromachined accelerometer using 100 μm thick SiOG substrate. The proposed accelerometer has a resonant frequency, 6 kHz. To reduce the off-axis sensitivity of the accelerometer, the mode characteristic of the accelerometer is investigated using ANSYS modal analysis. Because the accelerometer is fabricated using an SiOG substrate, it is expected to be integrated as one-chip IMU sensor with a gyroscope using an SiOG substrate.

1. Introduction

Inertial sensors are devices that convert an inertial force into a linearly scaled electrical signal with a given sensitivity. Until now, many inertial sensors have been developed and commercialized by various technologies. Micromachined inertial sensors, consisting of accelerometers and gyroscopes, are one of the most important types of silicon-based sensors. Micro-accelerometers alone have the second largest scales volume after pressure sensors [1]. Capacitive micro accelerometers have several advantages such as high sensitivity, low noise, stable DC characteristics, low drift, low power dissipation, and low temperature sensitivity [2]. Since the resolution of an accelerometer is proportional to the square of the natural frequency along the sensing direction, the natural frequency must be lowered to improve the resolution. Therefore, the larger mass and compliant spring is preferred. But, the compliant structure of the accelerometer increases the off-axis sensitivity and reduces the response time of the sensor [3].

In this paper, we adopt a high resonant frequency and parallel plate electrodes. Therefore, the proposed accelerometer is expected to have low off-axis sensitivity as well as fast response time

2. Experiment

2.1 Dynamics consideration

In micromechanical accelerometers, a proof mass with mass m is suspended to the substrate via a compliant suspension with spring constant k. When the substrate undergoes acceleration a, the proof mass exerts a force $F = ma$ on the suspension. For frequencies below the mechanical resonance of the spring mass system, this forces cause the suspension on deflect a distance x given by

$$x = \frac{F}{k} = \frac{m}{k}a = \frac{1}{\omega_0^2}a \tag{1}$$

Equation (1) shows that the scale factor depends only on the resonant frequency and is not affected by the choice of a large mass and stiff spring or a small mass and a compliant spring.

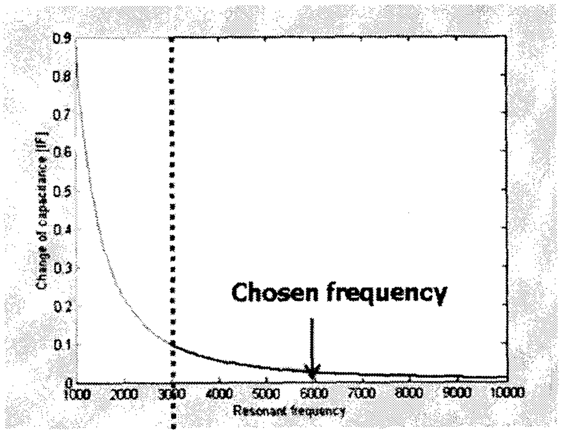


Figure 1. Relation between resonant frequency and change of capacitance

Figure 1 shows the relation between resonant frequency and the change of the capacitance. When the resonant frequency of the accelerometer is below 3 kHz, the change of the capacitance is large, but the accelerometer is weak to the noise from environment. The resonant frequency of the proposed accelerometer is 6 kHz. Therefore it is necessary to increase the sensitivity of the accelerometer by the high-aspect-ratio parallel plate electrodes.

2.2 Design of the structure

As described in figure 2, the proposed device has high-aspect-ratio single crystalline silicon structures, such as a proof mass, parallel plate electrodes and springs. Even though comb electrodes have a good linearity, parallel plate electrodes are used in this accelerometer to increase the sensitivity of the device. As the spring constant is high by the high resonant frequency, the displacement of accelerometer is small.

Using the parallel plate electrodes, the desired sensitivity and the good linearity are intended.

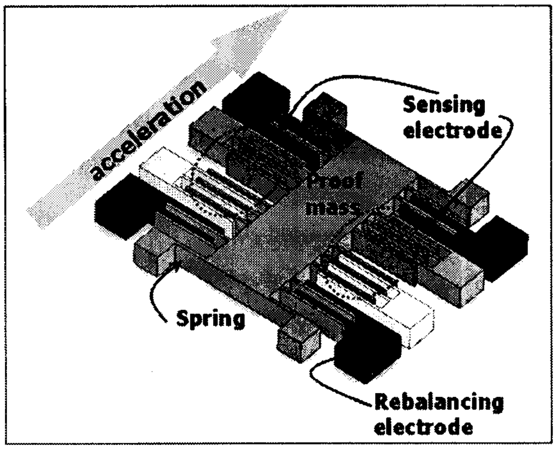


Figure 2. Schematic of the accelerometer

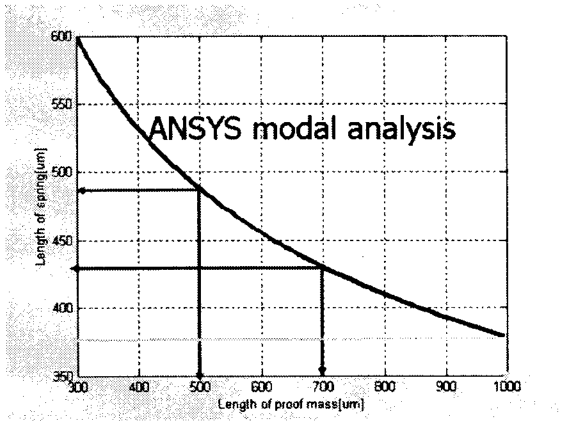
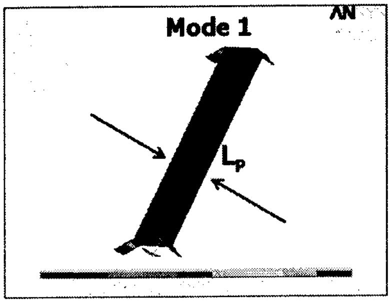


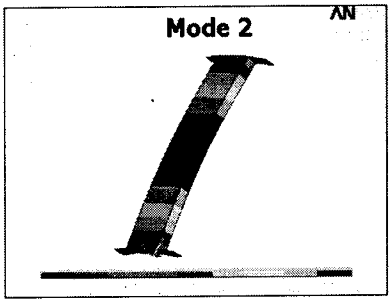
Figure 3. Relation of the length of proof mass and the length of spring with a resonant frequency, 6 kHz

The operation principle of this accelerometer is simple. When the external acceleration is applied to the proof mass of the accelerometer, the proof mass moves along to the direction of the acceleration. Then the gap between the parallel plates is changed and the acceleration can be sensed through the change of the capacitance. With the rebalancing electrode, a force balance technique can be adopted and we can also apply the external force as a test electrode.

Figure 3 show the relation of the length of proof mass and the length of spring with a 6 kHz resonant frequency . With this relation, we select three models, and then ANSYS simulation is performed to find the structure dimension with low off-axis sensitivity. Figure 4 shows the first and the second mode characteristic of the accelerometer. The first mode is translation motion and the second one is a bending motion of proof mass, respectively. Table 1 represents the results of the ANSYS simulation in the selected three models. Because a simple beam spring is used as a suspension structure, the ratio of the first mode resonant frequency and the second mode one is large. Therefore, the low off-axis sensitivity is expected in the proposed accelerometer. From these results, the length of proof mass, L_p, is set to 500 μm.



(a) 1st mode



(b) 2nd mode

Figure 4. Results of the ANSYS mode analysis

Table 1. Results of the ANSYS simulation

L_p[μm]	f_{r1}[Hz]	f_{r2}[Hz]	f_{r2}/f_{r1}
500	5629	72242	12.83
700	5739	70667	12.31
1000	5808	67698	11.66

2.3 Fabrication

The proposed accelerometer is fabricated by a single mask process, which uses a silicon-glass anodic bonded wafer [4]. Because the accelerometer 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 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 100 μm thick device.

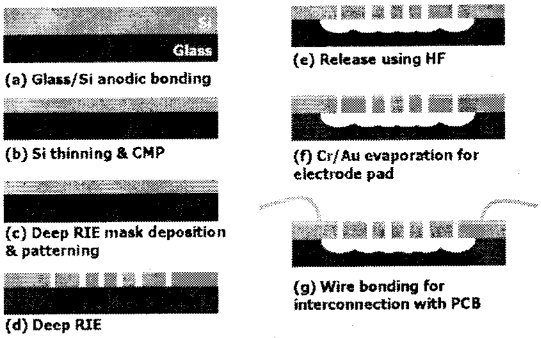
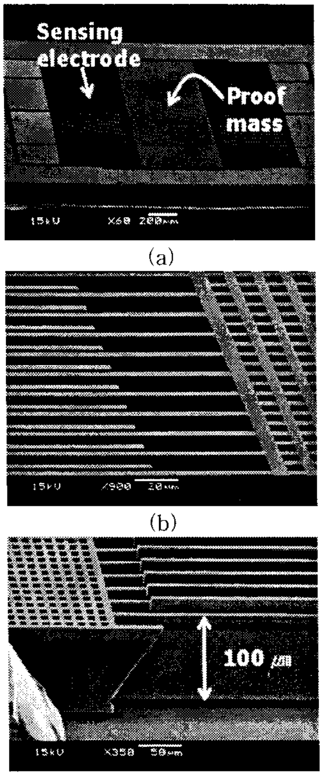


Figure 5. Process flow of the accelerometer

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.



(a)

(b)

(c)

Figure 6. Fabrication results, (a) fabricated micro accelerometer, (b) sensing electrode, (c) released structure with an 100 μm thickness

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.

Figure 6 shows the fabricated results. Figure 6 (a), (b) and (c) are SEM photographs of the fabricated micro accelerometer, enlarged view of the sensing electrode, and enlarged view of the released structure with an 100 μm thickness.

3. Conclusion

The micromachined accelerometer using an SiOG substrate is designed and fabricated. To improve the robustness on environmental noise, the resonant frequency of the accelerometer is set to 6 kHz. To increase the sensitivity, the parallel plate electrodes with a high-aspect-ratio structure are used. ANSYS simulation is performed to reduce the off-axis sensitivity. The proposed accelerometer is fabricated with a 100 μm thickness. The performance of the accelerometer will be measured. This accelerometer is expected to be integrated as an one-chip inertial measurement unit(IMU) sensor with a gyroscope using an SiOG substrate.

Acknowledgement

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