Structural analysis of performance optimization of high g accelerometer chip

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Abstract. Accelerometers based on micro-electromechanical systems (MEMS) technology are widely used due to their high cost performance and easy integration. However, there are still weaknesses in the mutual limitation of sensitivity and natural frequency in ordinary MEMS acceleration-sensitive structures. In this paper, a new type of piezoresistive acceleration-sensitive structure is optimized. The specific parameters are optimized by finite element simulation. Finally, the natural frequency of the sensitive unit reaches 2.039MHz and the sensitivity reaches 0.546μV / g.

1. Introduction
High-g acceleration sensors are mainly used in various types of collision and blast tests, especially in the field of weapon fuze. First, it is required to have a higher natural frequency, thereby improving its anti-interference ability; second, it is required to have a higher range while ensuring its sensitivity. But high natural frequency and high sensitivity are contradictory. With the development of micro-electromechanical systems (MEMS) technology, in order to alleviate the possibility brought about by this contradiction, this paper will optimize a three-axis high-g acceleration-sensitive chip to have a higher natural frequency while ensuring its sensitivity[1].

2. Sensor sensitive chip and its working principle
Acceleration sensors can be divided into piezoresistive, piezoelectric and capacitive based on their working principles[2]. A piezoresistive high-g acceleration sensor is designed in this paper. The specific working principle will be introduced below.

2.1. Sensitive cell structure
The structure of the sensitive unit is shown in Figure 1. The sensitive units all adopt a double-end fixed beam structure with microbeams. The prominent features of this structure are small volume, high sensitivity, and simple process. Compared with the traditional double-end clamped model, this structure adds a microbeam to measure its acceleration signal, which not only retains its advantages of high natural frequency, but also improves its sensitivity.
2.2. Sensor output circuit

When the sensitive unit is accelerated in the sensitive direction, the two microbeams on one side of the mass are compressed and the two microbeams on the other side are pulled. The corresponding two varistor resistances become larger, and each of them becomes smaller, and the power supply of the sensor can convert the change of the varistor of the sensitive unit into the output voltage of the sensor. According to the principle of the output circuit, the sensor sensitivity can be derived. The output circuit is shown in Figure 2.

![Figure 2. Wheatstone full bridge circuit schematic](image)

The sensitivity calculation formula is:

\[
S = \frac{V_{out}}{a} = \frac{\pi 44 |\sigma_l - \sigma_t| V_{in}}{2a} \tag{2.2}
\]

Where \( S \) is the sensitivity, \( V_{in} \) is the bridge voltage, \( \sigma_l - \sigma_t \) is the equivalent stress of the microbeam.

3. Optimal design of sensitive units

The main dimensions of the sensitive unit are three parts: mass, microbeam and support beam. In order to ensure the stability of the structure, the mass thickness of the mass and the supporting beam is equal. The last eight parameters to be optimized are mass length, mass width, support beam width, main structure thickness, microbeam length, microbeam width, beam thickness. Its main performance indicators are first-order natural frequency and microbeam stress. In order to measure its comprehensive performance, we use the P value (the product of the two values) to measure its simulation performance.

3.1. Impact of scaling on performance

Change the scaling ratio of the sensitive unit. The ratio is basically uniformly distributed from 0.5 to 1.5. A total of 7 sets of simulations have been done. The relationship between the expiration P value and the scaling ratio is shown in Figure 3.
It can be seen from the figure that the change amplitude is the largest near the zoom ratio of 0.85, and the change amplitude at both ends tends to be gentle. In order to meet the requirements of better sensor performance and consider the processing difficulty of silicon substrates, the data after the scaling factor of 0.75 is selected as the sensitive cell size.

3.2. Effect of mass size on performance

Use the same method as in section 3.1 to determine the specific size of the mass, and study the effect of the length and width changes of the mass on the P value. The curve of P value as a function of length and width is shown in Figures 4 and 5.

As can be seen from Figure 3, the P value first increases and then decreases with the increase of the length of the mass, and its change range is small on both sides, so in this case the ideal length of the mass is between 210μm and 235μm. Figure 4 shows the relationship between the P value and the width of the mass. From the figure, it can be seen that the change law is similar to that in Figure 4. The P value is small on both sides and large in the middle. Considering the size of the P value in Fig. 4 and Fig. 5 the width of the selected mass is 187.5μm and the length is 225μm.

3.3. Influence of thickness of main structure and size of support beam on performance

The overall dimensions of the sensitive unit and the length and width parameters of the mass have been determined. This section will determine the influence of the thickness of the subject structure and the width of the supporting beam on the performance of the sensitive unit. During the simulation, it is found that the thickness of the main structure and the width of the supporting beam have a greater impact on the natural frequency of the sensor. The two parameters will change under different proportions Its mode shape changes, so this section will study the effect of different support beam width on the performance of cotton stalk unit under different thickness of the main structure. Six sets of data were uniformly taken as the thickness of the main structure from 75 μm to 225 μm, and four sets of data were uniformly taken
as the thickness of the main structure from 45 μm to 67.5 μm. The obtained P value results are shown in Table 1.

| Body structure thickness /μm | Support beam width /μm |
|-----------------------------|------------------------|
|                            | 45          | 52.5       | 60  | 67.5       |
| 75                          | 28.78       | 27.35      | 26.38 | 25.35 |
| 105                         | 44.84       | 41.77      | 39.75 | 37.48 |
| 135                         | 49.78       | 49.83      | 50.31 | 49.03 |
| 165                         | 52.61       | 53.86      | 54.14 | 53.84 |
| 195                         | 57.11       | 56.49      | 56.50 | 55.48 |
| 225                         | 58.49       | 58.94      | 58.28 | 56.93 |

In the size range given above that meets the natural frequency of 2 MHz, a set of sizes with a higher P value is selected. From the P value data in Table 1, it can be seen that the largest P value in this range is 56.50, the corresponding main structure thickness is 195 μm, and the support beam width is 60 μm. At this time, its natural frequency is 2.039 MHz, the equivalent stress of the microbeam is 29.08 MPa, and the sensitivity is 0.546 μV / g from formula (2.2).

Finally, a set of dimensions of the sensitive unit is given according to the simulation process. The specific dimensions and performance parameters are shown in Table 2.

| parameter name                      | unit | value |
|-------------------------------------|------|-------|
| Mass length                         | μm   | 225   |
| Mass block width                    | μm   | 187.5 |
| Body structure thickness            | μm   | 195   |
| Support beam width                  | μm   | 60    |
| Support beam length                 | μm   | 150   |
| Microbeam section side length       | μm   | 12    |
| Microbeam length                    | μm   | 30    |

### 4. Conclusion

The structure of the high g impact-resistant piezoresistive acceleration-sensitive chip with microbeam was simulated and optimized by the finite element method. The results show that the microbeam structure can effectively improve the natural frequency and overload capacity of the chip.

### References

[1] Zhang Zhenhai, Li Kejie, Ren Xianren, et al. Design simulation and optimization of high overload 3D MEMS acceleration sensor sensitive chip [J]. Acta Armamentarii, 2008, 29 (6): 690 ~ 696.
[2] Li Yuan, Dong Peitao, Wu Xuezong, et al. Test method and experimental research of triaxial high-g accelerometer [J]. Journal of Transduction Technology, 2008, 21 (11): 1845 ~ 1847.
[3] Deng Tao. Research on Air Cannon Acceleration Overload Test Technology [D]. Nanjing: Nanjing University of Science and Technology, 2011.
[4] Tang Zhaoqian, Huang Wenhui. Handbook of Vibration and Shock [M]. Beijing: National Defense Industry Press, 1990: 84 ~ 89.
[5] The 13th Research Institute of China Electronics Technology Group. A silicon MEMS piezoresistive acceleration sensor [P]. Chinese invention patent, CN101118250A. 2008 ~ 09 ~ 13.