Effect of Slice Error of Glass on Zero Offset of Capacitive Accelerometer

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Abstract. Packaging process had been studied on capacitance accelerometer. The silicon-glass bonding process had been adopted on sensor chip and glass, and sensor chip and glass was adhered on ceramic substrate, the three-layer structure was curved due to the thermal mismatch, the slice error of glass lead to asymmetrical curve of sensor chip. Thus, the sensitive mass of accelerometer deviated along the sensitive direction, which was caused in zero offset drift. It was meaningful to confirm the influence of slice error of glass, the simulation results showed that the zero output drift was 12.3×10⁻³ m/s² when the deviation was 40μm.

1. Introduction

The capacitance accelerometer adopted symmetrical structure and the die-adhesive-substrate packaging method, the curve of accelerometer caused by the different thermal expansion coefficient [1]. Only the asymmetric curve of accelerometer could cause the output zero drift, Peng P studied the thermal drift of accelerometers with the consideration of the adhesive overflow, which indicated that the adhesive overflow leaded to 10% increase of thermal drift compared with accelerometers without adhesive overflow [2]. Lai L S studied the void in DG-3S (An electronic packaging adhesive) which also leaded to accelerometer zero output drift [3]. If the zero output drift of the accelerometer neened to further reduced, the slicing error in the package process should be considered yet, study on slice error of glass had been mentioned by some papers [4]. This paper focused on slice error of glass and discussed the influence on the accelerometer zero output when slice error of glass rang from 0μm to 40μm.

Slicing process was a step in MEMS device packaging, each chip unit was separated along the scratches on the glass, if glass scratches had deviation that the position of sensitive mass also had...
deviation yet. Chip and glass was adhered on ceramic substrate by DG-3S, the adhesive curing process needed to keep temperature of 60°C in incubator for two hours, then the temperature cooled down to the 20°C, because of the different thermal expansion coefficient, the three-layer structure curved in cooling process. As a result, the slice error of glass will leaded asymmetric curve of chip, which made the output zero offset.

2. Simulation

ABAQUS software was adopted in the Simulation, and half model of actual structure had been used in figure 1. The photo of micro-capacitance accelerometer structure was in figure 2, which was amplified 25 times, difference of \( d_1 \) and \( d_2 \) range from 0μm to 40μm had been set in simulation respectively, point A was the center of material contraction, the Young’s modulus, Poisson ratio and thermal expansion coefficient of materials was showed in table 1. According to the packaging process, temperature parameter had been set from 60°C to 20°C.

![Figure 1](image1.png)  ![Figure 2](image2.png)

**Figure 1** The ABAQUS model of micro capacitance accelerometer structure, point A was the contraction center. **Figure 2**. The micro capacitance accelerometer photo, the slice error of glass was marked by red line.

| Material | Young's modulus (GPa) | Poisson ratio | TCE        |
|----------|-----------------------|--------------|------------|
| Silicon  | 160                   | 0.22         | 2.6×10^-6  |
| DG-3S    | 4                     | 0.37         | 6×10^-5    |
| Glass    | 62.7                  | 0.2          | 3.25×10^-6 |
| Ceramic  | 360                   | 0.22         | 6.5×10^-6  |

3. Calculation

Each pair capacitance plate displacements of multiple nodes had been extracted from simulation for differential capacitance calculation. and the displacement of accelerometer showed in figure 3. Position changes of capacitance plate included displacement and angle [2], in figure 4. \( C_l \) and \( C_r \) expressed the left and right comb total capacitance respectively.
Figure 3 The capacitance plate deformation, $C_l$ and $C_r$ express the left and right comb total capacitance, respectively.

Basic formula for capacitance calculation expressed in equation (1), which calculated the left and right total capacitance plate, the effective common area $S$ was the shadow part in figure 4, which needed to extract the displacement of points form the simulation data, one method was provided to calculate the total capacitance [2].

$$C_i = \frac{\varepsilon\varepsilon_0 S}{d_i}$$

(1)

Where $\varepsilon$ is relative dielectric constant of air, $\varepsilon_0$ is dielectric constant, $\varepsilon_0=8.86\times10^{-12}\text{F/m}$, $S$ is the effective common area of capacitance plate, $d_i$ expresses the capacitance comb narrow gap. The results of $C_l$, $C_r$ under slice error of glass was shown in figure 5.

Figure 5 The left comb capacitance and right comb capacitance at different slice error of glass.

There was two reasons of the change of capacitance, firstly, the decrease of capacitance comb plate gap was caused by material constriction when temperature reduced, secondly, the decrease of capacitance plate effective common area was caused by accelerometer chip curved. When $d_1 > d_2$, the left anchor more closer to the contraction center than right anchor, the main reason for the change of capacitance was material contraction, which caused capacitance increase, while the right comb far away from contraction center, the main reason for the change of capacitance was curve of accelerometer chip, which caysed capacitance decrease, in figure 6. Hence because of the two ways of the capacitance changes caused complex capacitance variation, which leaded to zero offset of capacitive accelerometer. The formula of zero output expressed in equation (2).
\[ V_{\text{out}} = V G \frac{C_l C_r}{C_l + C_r} \]  
(2)

Where \( C_l \) and \( C_r \) is the left comb total capacitance and right total comb capacitance respectively, \( V \) is the amplitude of the open-loop voltage, \( G \) is the circuit gain coefficient. The acceleration output formula expressed in equation (3).

\[ S = V G \frac{mg}{kd} \]  
(3)

Where \( V \) is the amplitude of the open-loop voltage, \( G \) is the circuit gain coefficient, \( m \) is effective mass, \( g \) is the acceleration of gravity, \( k \) is total stiffness of the folded beams, \( d \) is capacitance plate gap, and the result of micro-capacitance accelerometer zero offset under slice error of glass range from 0μm to 40μm showed in figure 7.

![Figure 7](image)

Figure 7 The effect of deviation on the zero output drift at different slice error of glass.

4. Conclusion
According to simulation and calculation, the conclusion was as follows: the accelerometer zero output drift was \(12.3 \times 10^{-3} \text{ m/s}^2\), if slice error of glass was 40 μm. In figure 7, in section AB, the main reason of the accelerometer zero output drift was material contraction, the change rate of \( C_l \) larger than the change rate of \( C_r \), in the section BC, the main reason of the accelerometer zero output drift was capacitance plate effective common area changes, the change rate of \( C_l \) and \( C_r \) reached a balance, while in the section CD, the capacitance changes was caused by plate effective common area greater than the capacitance changes caused by material contraction, the accelerometer zero output drift was increased. The slice error of glass had no effect on the zero output drift of the accelerometer at nonsensitive direction, which shows in figure 2 \( S_1 > S_2 \).

The slice error of glass broke the balance of the change rate of \( C_l \) and \( C_r \) at the sensitive direction and caused the accelerometer zero output drift.

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