The Optimized Design of Accelerometer for the UV-LIGA Process

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Abstract. An optimized design of accelerometer was presented for the UV-LIGA process in this paper. Based on the FEA simulation of mechanical property and developing process, traditional comb-finger accelerometer was optimized for UV-LIGA process. The Finite Element Analysis (FEA) result of mechanical property demonstrates that the novel design offer the 2.96 times in sensitivity. Moreover, novel structure makes the hydrodynamics property during the developing process much better than that of traditional structure. It is great characters for the precision developing result and quality manufacture.

1. Introduction

The micro accelerometer which is based on the Integrate Circuit (IC) process and microfabrication process offers great characters, such as small volume, overload ability, easy to be integrate into other system, mass production, and so on, so that the Micro Inertial Measurement Unit (MIMU), which based on micro accelerometer, has been widely employed into automobile, aerospace and military fields. It also gains more and more attention from the researcher in the world [1].

At present, silicon surface process, bulk silicon process and LIGA process were widely employed in the accelerometer fabrication fields. For the sensitivity improvement, LIGA process was employed to obtain the high aspect ration structure [2]. The researchers from IMT (Institute of Microstructure Technology, Karlsruhe, Germany) have succeeded in the microfabrication of accelerometer with LIGA, and obtain the resolution of 1ug/Hz^{1/2} [3].

However, the expensive cost of X-ray Synchrotron radiation system and the complex process of X-ray mask has become the big obstacle in the LIGA process application [4]. UV-LIGA is an approach where a proximity UV aligner is used with a thick resist in place of the synchrotron x-ray exposure step [5]. After the lithography, electrodeposition and planarization are used to produce metal microparts or a metal replication tool [6].

Until now, most of design in micro accelerometer is based on the DRIE process. If we would like to employed UV-LIGA process in the microfabrication of micro accelerometer, we have to optimize the design followed the characters of UV-LIGA process.

2. The Finite Element Analysis in Sensitivity of Micro Accelerometer System

The traditional comb-finger structure was selected in our in our design and it is showed in figure 1. Compare with the DRIE process which based on SOI substrate, the novel process offers great characters on the stability of immobile comb-finger. The folding cantilever beam was employed as the flexibility structure, which was showed in figure 2.

Based on the mechanics principle, we can get the rigidity of folding beam in X direction, which is showed in equation (1) [7]:

\[ I = \frac{1}{12} bh^3 \]

\[ E = \frac{F}{A} \]

\[ F = \frac{1}{2} \rho V^2 \]

\[ V = \frac{1}{2} L \]

\[ A = \frac{1}{2} bh \]

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\[ A = \frac{1}{2} bh \]
\[ k_x = \frac{Eb^3h}{l^3} \]  

(1)

Figure 1. Schematics of comb-finger accelerometer.

Figure 2. The structure of Folding Beam.

Where: \( E \) is the Young’s Module, \( b \) is the width of beam, \( h \) is the height of beam, \( l \) is the length of beam.

From the figure 1, the system includes two folding beam which is connected in parallel, so that the rigidity of system is:

\[ K_x = 2k_x = \frac{2Eb^3h}{l^3} \]  

(2)

When the acceleration \( a \) is input into the system, the displacement of movement finger \( \Delta x \) can be calculated by Newton’s second law,

\[ \Delta x = \frac{ma}{K_x} = \frac{ml^3}{2Eb^3h}a \]  

(3)

Where, \( m \) is the mass of movement parts, \( a \) is the input acceleration.

From the equation (3), it can be easy to know that the length \( l \) and the width \( b \) of the beam offer great effective on the sensitivity of the system. The reduction of \( b \) and increase of \( l \) is much useful for the improvement of the sensitivity. But the dimension of system limits the improvement of beam length, and the reduction of beam width will increase the difficulty of fabrication. The average level of UV-LIGA process is the aspect ratio of 6:1, which the height is 100\( \mu \)m and width is 15\( \mu \)m.

3. The design optimizing based on the FEA of stress.

In order to meet the requirement of sensitivity improvement, Finite Element Analysis (FEA) which based on ANSYS software has been employed in the optimizing of design. The result is showed in figure 3. And the figure 3(b) demonstrates that the stress in the folding beam is
not uniform. It is concentrated in some areas where the deformation is much more obviously. It is marked by red arrow in Figure 3 (b).

![Figure 3. The FEA of stress in the folding beam](image)

As mentioned above, if decrease the width of beam directly, it will make the fabrication very difficult. So that, novel structure which is call “H” shape beam was employed in the folding beam design to improve the sensitivity of system by reduction of beam rigidity. The structure of “H” shape folding beam is showed in figure 4.

![Figure 4. The “H” shape folding beam](image)

Based on “H” shape folding beam, system can be benefit in the improvement of sensitivity, but not necessary to risk of beam width reduction. FEA which based on ANASYS software was employed to compare the rigidity of two kinds beam. The FEA result is showed in figure 5. When the acceleration of 1g was input, the displacement of comb-finger in structure showed in figure 2, (b=15mm) is 4.40nm (Figure 5 (a)); and the displacement of comb-finger in the structure showed in figure 4 (b=15mm, smallest in beam width is 5 mm) is 14.5nm (Figure 5 (b)). It is almost 3.3 times improvement base on the “H” shape folding beam.

![Figure 5. FEA Comparison of sensitivity base on two kind of beam shape](image)

**4. The Effect of Novel structure on the Development**

For the UV-LIGA process, if you would like to get the high aspect ratio structure for the sensitivity improvement, you have to achieve the deep trench structure in SU-8 at first. In that
case, not only the uniform exposure, but also the precision development is essential for the process. During the chemical development, fragment of the photoresist must be transported from the bottom of narrow features into development bath.

Development in recessed features depends on both species transport and surface reaction kinetics. Transport is rarely an issue in the development on flat surface where surface chemical concentrations can be maintained by stirring bath fluids or by moving the substrate relative to the bath. However, in development of patterned photoresist, even a very strong external flow is not effective in providing increased transport into recessed features having aspect ratios greater than five or ten. This is because the convective cell that circulates the fluid in the top of each feature penetrates only about one feature width. Additional counter-rotating convective cells are formed deeper within high aspect ratio features, but the circulation speeds decrease by nearly two orders of magnitude between successive cells [8]. Thus, high aspect ratio features are essentially stagnant over most of their height, while low aspect features are well-stirred throughout. This disparity of transport can be easily found in our experiment which is showed in figure 6.

![Figure 6](image)

**Figure 6** Comparison of the structure effect on development.

The fabrication result in Figure 6 are exposed and developed on one wafer at same experiment condition. The height is 1000 μm, and the gap and width of structure is 100 μm in figure 6(a), and 50 μm in (b) and (c). It can be easily found in the SEM images that the clear edge in (a) and (b), but obviously residual photoresist in (c). It means that the exposure process is all right and the residual photoresist in (c) is led by transport limitations of photoresist fragment in deep trench.

Following hydrodynamics, the photoresist species transport is not decided only by the velocity, but also the trench structure. In order to have clear understanding in the development process, the Finite Element Analysis (FEA) is employed to simulate the species transport during the development. Two kind of deep trench structure are selected to compare the hydrodynamics effect on development.
The schematic of two kinds of trench is demonstrated in figure 7, the length of trench is 100µm, and depth is 50 µm. The width is 8 µm in figure 7(a), and the minimum in width is 5 µm and other area is 15 µm. We define that the sample is immerse in the developer, and the velocity of developer is 3m/s, the flow is along the length direction of trench.

**Figure 7.** The schematic of two kind of trench.

The numerical calculation result is showed in figure 8. The velocity in most area of (a) is slower than 233mm/s, only in very small area on top of trench is 350mm/s. And there is a quite big area at the bottom or edge of trench where the flow rate is almost 0. However, the velocity in (b) is quite different, most area is over 477.1, and the center area is better than 895 mm/s, it is almost 2-4 times of the velocity in (a). Moreover, the stream distribution in (b) is more suitable for the development process. There is only very small area at flow rate. The

**Figure 8.** The streamline result of FEA.

**Figure 9.** The SEM image of the micro accelerometer SU-8 moulds.
simulation result demonstrates that the structure in (b) offers great character of development. Although the feature is smaller in (b) than in (a), the flow rate is much faster than it. It means that it is much easier to get the fine development result under same developing condition.

The figure 9 is the SEM image of the micro accelerometer SU-8 moulds for UV-LIGA process. It is followed the design which is discussed in this paper. The novel structure offers positive effect on the developing of narrow trench structure, and clear edge has been achieved successfully. The developing time is also much shorter than previous.

5. Conclusion
Most design of the micro accelerometer system is for the DRIE process. The design which talked in this paper is focus on the property of LIGA, especially the development process, and optimized by the numerical calculation result. The FEA simulation result and experiment demonstrates that the optimized design offers great characters in sensitivity of system and positive effect on developing process.

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