A Study on Mechanical Structure of a MEMS Accelerometer Fabricated by Multi-layer Metal Technology

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Abstract

This paper reports the evaluation results of the mechanical structures of MEMS (micro electro mechanical systems) sensor implemented in the integrated MEMS inertial sensor for a wide sensing range from below 0.1 G to 20 G (1 G = 9.8 m/s\(^2\)). To investigate the mechanical tolerance, a maximum target acceleration of 20G was applied to the sub-1G sensor which had the heaviest proof mass of all sensors had. The structure stability of Ti/Au multi-layered structures was also examined by using Ti/Au micro cantilevers. The results showed that the stoppers effectively functioned to prevent the proof mass and the springs from self-destruction, and that the stability of Ti/Au structures increased with an increase in width. Those results suggest that the proposed stopper and spring structures could be promising to realize MEMS sensors.

1. Introduction

Recently, wide sensing range and high resolution are required for MEMS accelerometers \cite{1,2}, and hence we have proposed an integrated CMOS (complementary metal-oxide semiconductor) – MEMS accelerometer \cite{3}, as shown in Fig. 1. Our previous studies showed the miniaturization method and the fabrication process of the sensor \cite{4,5}.

In this paper, we present the evaluation results of the mechanical structures of the sub-1G sensor implemented as an integrated MEMS for a wide sensing range.

2. Sensor Design and Stopper Effect

2.1 Sensor Design Concept

Fig. 2 shows the design concept of MEMS sensor made of electroplated metals. We designed a single-axis MEMS capacitive inertial sensor to be implemented in the proposed

Fig. 3 Chip view of the integrated MEMS inertial sensor.
sensor as shown in Fig. 1. Stoppers are used to limit the motion of the proof mass when an excess acceleration is applied to the device. The MEMS sensor is fabricated by the post-CMOS gold electroplating process as reported elsewhere [3]. Fig. 3 is the chip view of the developed integrated MEMS sensor with a sub-1G sensor. Fig. 4 shows SEM (scanning electron microscope) images of device D, where the mechanical stopper and the spring are located at the corner of the proof mass. The design parameters of the integrated sensor are presented in Table I, which shows the proof mass of sub-1G sensor (device A) is the heaviest possible and is subject to the largest inertial force under acceleration input.

### 2.2 C-G Characteristics

We measured the C-G characteristics (capacitance responses associated with input acceleration) of the developed sub-1G sensor; the experimental setup is described in Fig. 5, and the measured C-G data is shown in Fig. 6. The C-G results show the feasibility of sub-1G capacitive sensing.

<table>
<thead>
<tr>
<th>Device</th>
<th>Mass area (μm²)</th>
<th>Mass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>±0.1</td>
<td>2.069 × 2417</td>
</tr>
<tr>
<td>B</td>
<td>±1</td>
<td>909 × 909</td>
</tr>
<tr>
<td>C</td>
<td>±3</td>
<td>677 × 677</td>
</tr>
<tr>
<td>D</td>
<td>±10</td>
<td>561 × 561</td>
</tr>
<tr>
<td>E</td>
<td>±20</td>
<td>329 × 329</td>
</tr>
</tbody>
</table>

Table 1. Characteristics of the integrated sensor.

Fig. 6 Measured C-G characteristics of sub-1G sensor.

Fig. 7 Measured capacitance response of sub-1G sensor at the input acceleration from 0.1 G to 20 G.

### 2.3 Stopper Effect: input acceleration from 0.1 G to 20 G

Input acceleration range was experimentally evaluated by applying the maximum target acceleration of 20 G to the integrated MEMS inertial sensor. Fig. 7 shows the measured C-G characteristics of the sub-1G sensor from 0.1 G to 20 G. The sub-1G sensor can be a gauge of mechanical robustness, since it has the heaviest proof mass among other devices in the chip, and hence is subjected to the largest inertial force. We confirmed that the sub-1G sensor functioned without mechanical failure; excess trip of the proof mass could be limited by the stoppers.
3. Structure Stability

To evaluate the structure stability, we employed Ti/Au multi-layered micro cantilevers, as shown in Fig. 8, developed by the same metal formation process as used for the sub-1G sensor. Fig. 9 shows the fabrication process of the cantilever. We measured height \( h \) of the micro cantilevers at different points from the fixed end by using the optical microscope (VHX-5000, Keyence); the cantilever width was designed to be 5 \( \mu \)m, 10 \( \mu \)m, and 15 \( \mu \)m, and the length \( l \) was varied from 100 \( \mu \)m to 500 \( \mu \)m with a 100-\( \mu \)m step. The length of the cantilever is the same order of magnitude as those of springs used for the sub-1G sensor. Standard deviation of the height was calculated from the measured results, as shown in Fig. 10. The structure stability increased as the cantilever width increased.

4. Conclusion

We measured the C-G characteristics of the sub-1G sensor at input acceleration from 0.1 G to 20 G. The C-G results show the feasibility of sub-1G sensing and the input acceleration range up to 20 G with the help of the stoppers. The structure stability of Ti/Au multi-layered structures was also evaluated by using micro cantilevers; the cantilevers demonstrated the increased stability with an increase in the width. These results suggest that the proposed stopper and spring structure could be promising to realize reliable MEMS sensors.

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References