ABSTRACT

The anchor design for resonant mass sensor cantilevers has an important effect on structural dynamic behavior. We investigated five anchor designs and determined their effect on static deflection as well as resonant frequency. The first two designs are the simplest and most commonly used. The third and fourth designs, observed in the literature, add material to the anchor pillar by encapsulating sacrificial material. The fifth design, one of our own, adds two “feet” that extend alongside the cantilever. Static deflection under an applied uniform pressure was predicted using finite element analysis. Resonant frequencies for the first several vibration modes were also predicted. The results suggest that the anchor rigidity has a significant effect on static deflection. The most effective design had a static deflection approximately one half of that for the simplest design. The effect on resonant frequency is slightly more modest but still significant.

INTRODUCTION

A MEMS resonant mass sensor consists of a micromachined cantilever beam coated with a substance that binds to a chemical vapor of interest. Binding to the cantilever increases its mass and reduces its natural frequency. Detection of resonant frequency change has proven to be a highly sensitive approach to chemical vapor sensing. The cantilevers can be fabricated in an array, and the coatings varied to improve reliability and selectivity. Sensitivity improves as stiffness increases, mass decreases, and damping decreases. Our goal is to develop optimal cantilever designs that lead to an order-of-magnitude improvement in sensitivity.

A micromechanical anchor is the support structure that joins the microstructure with the substrate. Because the anchor is typically made up of one film layer, its rigidity is very low. However, when modeled, the anchor is usually assumed to be a fixed boundary condition. As a result, micromechanical device performance may differ significantly from model prediction.

Several variations on anchor design have been previously analyzed and tested [1,2]. Available fabrication processes limit the number of possible designs. In this paper we propose a new anchor design and compare its performance to previously studied anchor designs.

ANCHOR GEOMETRIES

Figure 1 illustrates three types of anchor structures that have been used for cantilevers. Geometry A would be created by depositing polysilicon over a sacrificial layer (located in the space below the cantilever) and then etching away polysilicon beyond the fixed end and free end of the cantilever. Finally, the sacrificial layer under the cantilever would be etched away. Geometry B is created with the same process except the etch boundary near the fixed end of the polysilicon is moved farther to the left. Geometry C has a thicker anchor structure. It could be created by depositing polysilicon over a sacrificial layer (located in the space below the cantilever) and then etching away polysilicon beyond the fixed end and free end of the cantilever. Finally, the sacrificial layer under the cantilever would be etched away. Geometry B is created with the same process except the etch boundary near the fixed end of the polysilicon is moved farther to the left.

Geometry C has a thicker anchor structure. It could be created by depositing material of the sacrificial layer in the anchor region (as well as under the cantilever) and then encapsulating it with polysilicon. The conformal deposition of polysilicon leaves a small dimple. As in the first two designs, the polysilicon is etched to its final geometry. The exposed sacrificial material under the cantilever is then removed while the encapsulated sacrificial material remains.

Figures 2-5 show the meshes for the three anchor designs introduced in Figure 1. Note that geometry C has two versions. All cantilevers are 100 µm long, 10 µm wide and 3 µm thick.
FIGURE 1. Three anchor designs observed in the literature.

A new anchor geometry is proposed as shown in Figure 6. The design is similar to C2 with the addition of two feet to the sides of the cantilever. Like geometries C1 and C2, the thick anchor structure could be created by encapsulating material from the sacrificial layer.

Finite element analysis of these five designs (A, B, C1, C2, and D) was carried out using ANSYS software. Solid, triangular elements were used. The software automatically chose the appropriate mesh unit size. Shell elements could not be used because the section thickness of the structure is not uniform. Instead we chose the element type of solid 45 for its accuracy. The following properties of polysilicon were assumed: Young’s modulus = 130 GPa, Poisson’s ratio = 0.278, and density =2330 kg/m$^3$.

FIGURE 2. Mesh for geometry A; anchor width w is 10 µm, length l is 3, and height h is 8 µm.

FIGURE 3. Mesh for Geometry B; w = 10 µm; vertical part of anchor has length $l_v$ of 3 µm and height $h_v$ of 8 µm; horizontal part of anchor has length $l_h$ of 20 µm and height $h_h$ of 3 µm.

FIGURE 4. Mesh for Geometry C version 1; w = 20 µm, $l = 8$ µm and $h = 8$ µm.

FIGURE 5. Mesh for Geometry C, version 2; w = 30 µm, $l = 23$ µm and $h = 8$ µm.
Figure 6. Mesh for new geometry D; large rectangular part of anchor is 23 µm long, 30 µm wide and 8 µm tall; each foot is 20 µm long, 5 µm wide and 8 µm tall.

SIMULATION RESULTS
Static displacement and resonant frequencies were determined for each of the five designs. Note that all five designs have the same cantilever dimensions.

Displacement
A uniform pressure of 1000 Pa was applied to the top of the cantilever and the tip displacement was calculated. Table 1 summarizes the tip displacements for the five designs.

Table 1. Maximum displacement due to applied pressure of 1000 Pa.

<table>
<thead>
<tr>
<th>Design</th>
<th>Displacement, nm</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>15.0</td>
</tr>
<tr>
<td>B</td>
<td>13.7</td>
</tr>
<tr>
<td>C1</td>
<td>7.54</td>
</tr>
<tr>
<td>C2</td>
<td>7.47</td>
</tr>
<tr>
<td>D</td>
<td>7.16</td>
</tr>
</tbody>
</table>

The results clearly show the dramatic effect that anchor design has on rigidity. Anchor B has higher rigidity than anchor A because its pillar area is larger. Design C1 produces a significant improvement over designs A and B. The larger pillar area of C2 produces negligible improvement over C1. The rigidity of the new design D is slightly better than the two C designs.

Resonant Frequency
The finite element models were then used to predict the resonant frequencies of the first several vibration modes for each of the cantilever designs. Figures 7-10 illustrate four vibration modes for design D.
FIGURE 10. Fifth vibration mode of design D.

Figure 11 shows the frequency response function for design D. The first four resonant peaks are at approximately 0.8 MHz, 1.5 MHz (damped and not visible), 5.8 MHz, and 8.9 MHz (barely visible).

FIGURE 11. Frequency response for design D.

Figure 12 compares the resonant frequencies of the first four modes for the five designs. The resonant frequencies are noticeably higher for the last three designs, as expected from the static deflection results. Keep in mind that the actual devices will behave somewhat differently as this simulation did not take damping into consideration.

FIGURE 12. Comparison of resonant frequencies for the five anchor designs.

CONCLUSIONS

High stiffness and resonant frequency are desirable for many MEMS devices including resonant mass sensors. During the design process, the anchor is often assumed to be perfectly rigid, and this leads to inaccurate predictions of device performance. With finite element analysis of five designs we have shown that anchor design has a significant effect on static displacement. The most effective design had a static displacement of approximately one half of that for the simplest design. The effect on resonant frequency is slightly more modest but still significant. One way to produce the larger, thicker anchors that give the best performance is to encapsulate material from the sacrificial layer.

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REFERENCES
