Design and Analysis of Thermal Expansion in different Geometries for MEMS Actuators

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Abstract—A MEMS thermal actuator is a micromechanical device that typically generates motion by thermal expansion. In this paper we have studied the thermal expansion of different shapes of thermal actuator and implemented using COMSOL tool. Different shapes are designed and analyzed. Rectangular, triangular and U shaped actuator is designed and implemented.

Keywords: MEMS, FEM, COMSOL, THERMAL EXPENSION, 3D

I. INTRODUCTION

The greatest promise of microelectromechanical systems (MEMS) lies in the ability to produce mechanical motion on a small scale. Such devices are typically low power and fast, taking advantage of such microscale phenomena as strong electrostatic forces and rapid thermal responses. MEMS-based sensors have been widely deployed and commercialized. MEMS technologies also show prospective applications in optics, transportation aerospace, robotics, chemical analysis systems, biotechnologies, medical engineering and microscopy using scanned micro probes. A MEMS thermal actuator is a micromechanical device that typically generates motion by thermal expansion amplification. A small amount of thermal expansion of one part of the device translates to a large amount of deflection of the overall device. Usually fabricated out of doped single crystal silicon or polysilicon as a complex compliant member, the increase in temperature can be achieved internally by electrical resistive heating or externally by a heat source capable of locally introducing heat. Microfabricated thermal actuators can be integrated into micromotors.

II. DESIGN AND ANALYSIS

Thermal expansion is the type of actuator i.e. when we change temperature the material expands. In this paper we have designed and analyzed three different geometries they are rectangular, triangular and U shape.

1. Designing rectangular shape

Rectangular shape consist of eight straight rectangles in parallel with dimension of 10µm, 110µm, 10µm width, length and height respectively. With a gap of 20µm and 10µm between alternating rectangles as shown in figure 1.

By applying fixed boundaries to lower base of the rectangle so that the expansion only takes place in upwards direction. The region is shown in figure 2 colored grey. The remaining region shown as blue where heat flows can take place.

The heat flux is given conduction only. The heat source is a constant heat source of 1*10^8 W/m^3. The air cooling at the boundaries is expressed using a constant heat transfer coefficient of 7000 W/m^2K and an ambient temperature of 298 K. The expression for thermal expansion requires strain reference temperature for the copper beryllium alloy, which in this case is 293 K. [6]
By applying fixed boundaries to lower base of the rectangle so that the expansion only takes place in upwards direction. The region is shown in figure 6 colored violet. The remaining region shown as brown where heat flows can take place.

Figure 4 shows the meshed geometry. Mesh generation is one of the most critical aspects of engineering simulation. Too many cells may result in long solver runs, and too few may lead to inaccurate results. COMSOL Meshing technology provides a means to balance these requirements and obtain the right mesh for each simulation in the most automated way possible.

Figure 5: U Shape Geometry

2. U shape geometry

U shape too consist of eight straight rectangles in parallel with dimension of 10µm, 100µm, 10µm width, length and height respectively. A curve of radius of 20µm is drawn above two respective rectangles. With a gap of 20µm and 10µm between alternating rectangles as shown in figure 5.

Figure 6: Fixed boundaries (lower base)

Figure 7 shows applying of structural materials to the geometries seen in green color. A copper beryllium alloy is applied to the device to analyze the thermal expansion of the geometry. The thermal stress physics is applied to the device to analyze displacement of the device due to thermal expansion of device.

Figure 7: Applying material

Figure 8 shows the meshed geometry of U-shape

Figure 8: meshed geometry
3. Triangular geometry

Triangular shape consist of four 3D triangles above a rectangular base as shown in figure 9.

![Figure 9: Triangular Shape Geometry](image)

By applying fixed boundaries to lower base of the rectangle so that the expansion only takes place in upwards direction. The region is shown in figure 10 colored violet. The remaining region shown as brown where heat flows can take place.

![Figure 10: Fixed boundaries (lower base)](image)

Figure 11 shows applying of structural materials to the geometries seen in green color. A copper beryllium alloy is applied to the device to analyze the thermal expansion of the geometry. The thermal stress physics is applied to the device to analyze displacement of the device due to thermal expansion of device.

![Figure 11: Applying material](image)

III. RESULTS

When we use 298K as external temperature then the maximum displacement is 0.022 µm for triangular geometry. The following figure 13 shows the total displacement in the device.

![Figure 12: meshed geometry](image)

![Figure 13: Displacement of the Device](image)

The following figure shows the displacement of a curve that follows the top inner edges of the device from left to right.
When we use 298K as external temperature then the maximum displacement is 0.0474 µm for U shape geometry. The following figure 15 shows the displacement in the device.

![Displacement vs Position graph](image14.png)

**Figure 14:** Displacement vs Position graph

When we use 298K as external temperature then the maximum displacement is 0.045 µm for rectangular geometry. The following figure 17 shows the total displacement in the device.

![Displacement of the Device](image17.png)

**Figure 17:** Displacement of the Device

The following figure shows the displacement of a curve that follows the top inner edges of the device from left to right.

![Displacement vs Position graph](image18.png)

**Figure 18:** Displacement vs Position graph

The following figure shows the displacement of a curve that follows the top inner edges of the device from left to right.

![Displacement of the Device](image15.png)

**Figure 15:** Displacement of the Device

The following figure shows the displacement of a curve that follows the top inner edges of the device from left to right.

![Displacement of the Device](image16.png)

**Figure 16:** Displacement vs Position graph

IV. CONCLUSION

Here we concluded that thermal expansion shows better result when we use U shape geometry with expansion of 0.0474 µm. It is clear from all graph that are shown above that when we are using rectangular geometry then expansion is 0.045 µm which is nearly equal to U shape geometry and triangular geometry produces less expansion of 0.022 µm. As we wanted more displacement for actuation from above result we should use U shape geometry but with not much difference in displacement with rectangular geometry and simple fabrication steps rectangular geometry should be preferred.

REFERENCES


