MODELING AND COUPLED FIELD ANALYSIS OF POLYSILICON MICRO GRIPPER USING FEA

N. Arun Kumar¹, Gunasekhar Reddy² and Bezawada Sreenivasulu³

¹PG Student, Madanapalli Institute of Technology and science, Madanapalli, India
Email: kumararun323@gmail.com
Assistant Professor, MITS, Madanapalle, India
Email: gunamits@gmail.com

ABSTRACT

Micro-Electro Mechanical Systems (MEMS) is one of the most advanced technology developments of the recent trend. In this paper modeling of MEMS microgripper is done in pro-E. Coupled-field analysis that includes for the integration of (coupling) electric, thermal and structural fields in Ansys to determine structural displacements at end effector of microgripper, in addition to determine the temperature distribution of the microgripper.

Keywords: MEMS, Micro Gripper, Coupled Field Analysis, Ansys

INTRODUCTION

Micro electromechanical systems (MEMS) is a technology of miniaturization that has been largely adopted from the integrated circuit (IC) industry and applied to the miniaturization of all systems not only electrical systems but also mechanical, optical, fluid, magnetic, etc. MEMS are, in their most basic forms, diminutive versions of traditional electrical and mechanical devices – such as valves, pressure sensors, hinged mirrors, and gears with dimensions measured in microns – manufactured by techniques similar to those used in fabricating microprocessor chips. The first MEMS products were developed in the 1960s, when accurate hydraulic pressure sensors were needed for aircraft. Such devices were further refined in the 1980s when implemented in fuel-injected car engines to monitor intake manifold pressure.

In the late 80s, MEMS accelerometers for car airbags were developed as a less expensive, more reliable, and more accurate replacement for conventional crash sensor. Taking the spotlight today are optical MEMS (also known as Micro Opto-Electro Mechanical Systems or MOEMS primarily micro mirrors, which are used as digital light processors in video projectors and as well as switches in optical network equipment. After extensive development, today’s commercial MEMS – also known as Micro System Technologies (MST), Micro Machines (MM), or M3 (MST, MEMS & MM) – have proven to be more manufacturability, reliable and accurate than their conventional counterparts. However the technical hurdles to attain these accomplishments were often costly and time-consuming, and current advances in this technology introduce newer challenges still. Because this field is still in its infancy, very little data on design, manufacturing processes or liability are common or shared.
As the race for miniaturization continues, there present a need to design and develop a micro gripping device that is capable of gripping small objects (in the microns) accurately and without causing damages to the gripped object. Such a micro gripper device also has its potentials in the biomedical field. Researches on the micro gripper reveals that most of the current micro grippers proposed by other research institutions are only capable of achieving small opening of the gripper tips, hence limiting the range of size of objects that can be gripped and handled. Furthermore, most of the proposed micro gripper are without force sensing capabilities and requires varying amount of assemblies that are difficult and expensive to do.

**Benefits of MEMS**

Because of increase in micromachining technology, hundreds of MEMS can be made from a single 8-inch wafer of silicon. Below is an image which shows how small MEMS are in comparison to a dime. Because an entire system can be made this small and in such quantities, prices are reduced for products which incorporate this technology. MEMS also have no moving parts, so they are much more reliable than a macro system. Because of the reduced cost and increased reliability, there is almost no limit to what MEMS can be used for.

**Current Challenges**

MEMS are currently used in low or medium-volume applications. Some of the obstacles preventing its wider adoption are

**Limited options**

Most companies who wish to explore the potential of MEMS have very limited options for prototyping or manufacturing devices have no capability or expertise in micro fabrication technology. Few companies will their own fabrication facilities because of high cost. A Mechanism giving smaller organizations responsive and affordable access to MEMS is essential.
Fabrication knowledge required

Currently designer of a MEMS device requires a high level of fabrication knowledge in order to create a successful design. Often the development of even the most mundane MEMS device requires a dedicated research effort to find a suitable process sequence for fabricating it. MEMS device design needs to separate from the complexities of the process sequence.

Packaging

MEMS packaging is more challenging than IC packaging due to the diversity of MEMS devices and the requirement that many of devices be in contact with their environment.

OBJECTIVE OF THE WORK

- To obtain 3-D model of MEMS micro gripper using Pro-E software.
- To couple the fields like electrical to thermal, thermal to mechanical to contemplate true condition using ANSYS.
- To determine the structural displacements at end effector and temperature distribution of the MEMS microgripper.

ANALYSIS

Coupled field analysis

A coupled field analysis is a combination of analyses from different engineering disciplines that interact to solve a global engineering problem. Hence, we often refer to a coupled -field analysis as a multi physics analysis. In coupled field or multi physics problems the input of one field analysis depends on the results from another analysis that is coupled with it.

For example

In a fluid-structure interaction problem, the fluid pressure causes the structure to deform, which in turn causes the fluid solution to change. This problem requires iterations between the two physics fields for convergence. Some of the applications in which coupled -field analysis may be required are pressure vessels (thermal-stress analysis), fluid flow constrictions (fluid-structure analysis), induction heating (magnetic-thermal analysis), ultrasonic transducers (piezoelectric analysis), magnetic forming (magneto-structural analysis), and micro-electromechanical systems (MEMS).

In ANSYS, coupled field analysis was carried out where the electrical, thermal and structural analysis is coupled together and through this analysis the displacement and the temperature distribution of the micro gripper can be determined.

The table 1 describes the material properties of Polysilicon that have to be fed as input parameters in ANSYS material model with which the micro gripper was made up of.

<table>
<thead>
<tr>
<th>S.NO</th>
<th>Young's Modulus (Mpa)</th>
<th>Poisson’s ratio</th>
<th>co-efficient of thermal expansion (µ-K)</th>
<th>Thermal Conductivity (Pw/µm² K)</th>
<th>Resistivity (tera ohm-µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>169X10³</td>
<td>0.22</td>
<td>2.9X10⁻⁶</td>
<td>15.4X10⁶</td>
<td>2.3X10⁻¹³</td>
</tr>
</tbody>
</table>
Modeling and Simulation of Micro Gripper

The Micro Gripper is split into 4 parts.

They are as follows,

- Arm of the gripper
- Displacement transfer element
- Thermal expansion element
- Base element

Four parts are modeled in part module based on the given dimensions shown in below fig. The micro gripper of the required dimension was modeled in Pro-E using part module and assembling them using assembly module then converting the file into IGES format. Then the IGES file is imported into Ansys and the required material data was assigned to the micro gripper model according to the material with which the micro gripper was made up of. The maximum displacement produced by the gripper was noted by varying the voltage input to the terminals.

![Fig.2 Dimensions of the micro gripper](image1)

![Fig.3 Model developed in Pro-E](image2)

Applied boundary conditions in ANSYS for carrying out displacement measurement

1. The contact pad anchored i.e. the degree of freedom was made zero in all three dimensions.
2. The thermal expansion element temperatures are maintained at 30 degree Celsius.
3. The required voltage was applied across the contact terminals to actuate the thermal expansion element in order to open the tip of the gripper.

RESULTS

The X-displacement of the micro gripper was determined to find the maximum horizontal displacement produced by the gripper due to the applied voltage, the figure shown below represents the X-displacement profile of the micro gripper and the color scale at the bottom of the figure represents the displacement range the micro gripper undergone on actuation in a VIBGYOR color pattern with the violet color representing the region of minimum displacement and the red color representing the region of maximum displacement. We can observe from below figures that the maximum displacement occurs at the top right corner of

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the gripper tip. Below figures (4-9) are the displacements occurred due to the applied voltage.

**Tip Opening Displacement for Different Voltages**

**Fig 4.** Tip opening displacement for 1 V

**Fig 5.** Tip opening displacement for 2 V

**Fig 6.** Tip opening displacement for 3 V

**Fig 7.** Tip opening displacement for 4 V

**Fig 8.** Tip opening displacement for 5 V

**Fig 9.** Tip opening displacement for 6 V

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Temperature Distribution

Fig 10. Temperature distribution for 1 V

Fig 11. Temperature distribution for 2 V

Fig 12. Temperature distribution for 3 V

Fig 13. Temperature distribution for 4 V

Fig 14. Temperature distribution for 5 V

Fig 15. Temperature distribution for 6 V
### Table 2. Max displacement & max temperature for the applied voltage for polysilicon material

<table>
<thead>
<tr>
<th>S.No</th>
<th>Voltage on Terminal</th>
<th>Max displacement (µm)</th>
<th>Max temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>0.015671</td>
<td>36.1095</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>0.028763</td>
<td>91.1162</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>0.050583</td>
<td>191.423</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>0.081132</td>
<td>332.057</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>0.120408</td>
<td>513.086</td>
</tr>
<tr>
<td>6</td>
<td>6</td>
<td>0.168413</td>
<td>734.509</td>
</tr>
</tbody>
</table>

### CONCLUSIONS

In this paper several input voltages are applied to the microgripper made of polysilicon material. The tip opening displacement for different values of applied voltages and the maximum temperature generated due to the applied voltage are investigated. It is observed that based on the object length which we have to grip the required voltage should be applied, on increasing the voltage applied to the gripper the temperature generated in the gripper also increases. The applied voltage, the tip opening displacement and temperature distribution are tabulated in above table.

### REFERENCES

**Journal Papers**