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# Modeling Su8 Based Micro Gripper with Constant Heat Flux and Stress Analysis

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**Abstract**—This paper presents modeling of thermal micro actuators based on SU-8 polymer is described. Here the development of a new microgripper which can realize a movement of the gripping arms with positioning and manipulating of the holded object. The polymeric microgripper electro thermo-mechanical actuated, using low actuation voltages, designed for SU-8 polymer analysis is presented. The electro-thermal microgrippers were designed and optimized using finite element simulations. Electro-thermo-mechanical simulations based on finite element method were performed for temperature and stress analysis.

**Keywords—** Micro-gripper, Su8 polymer.

## 1. INTRODUCTION

Thermal micro-actuators are solution to the need for large-displacement, gentle handling force, low-power MEMS actuators. Applications of these devices are micro grippers ,micro-relays, assembling and miniature medical instrumentation. In this paper the development of thermal micro actuators based on SU-8 polymer is described [1]. Here the development of a new microgripper which can realize a movement of the gripping arms with positioning and manipulating of the holded object. The polymeric microgripper electro thermo-mechanical actuated, using low actuation voltages, designed for SU-8 polymer analysis is presented. The electro-thermal microgrippers were designed and optimized using finite element simulations. Electro-thermo-mechanical simulations based on finite element method were performed for each of the model in order to compare the results. Here solid in plain view is visualized i.e. many elongated structures can be modeled effectively using 2D representations of their cross sections. A typical assumption is the plane strain approximation, which implies that all out-of-plane strain components are zero.[2] This assumption is valid when the out-of-plane deformation is restrained; for example, when the ends of the structure are fixed. However, in many cases, the structure is free to expand in the out-of-plane direction. Joule Heating and Thermal Expansion is a class of multi physics simulation which involves coupling electrical conduction, heat transfer and structural analysis. Traditional application includes reliability analysis in electronics packaging and MEMS actuators. The thermal stress analysis id done on the model, we need to extend it by coupling the temperature field to a structural mechanics analysis. The features and equations required for the stress analysis and general linear- and nonlinear solid mechanics are contained within the Solid Mechanics interface in the Structural Mechanics FEM Module. These equations are the key to analyzing thermal expansion.

Thermal loads:

$$\sigma = D\varepsilon_{el} + \sigma 0 = D(\varepsilon - \varepsilon_{th} - \varepsilon_0) + \sigma_0$$

In this equation, σ is the stress, D is the elasticity matrix, and ε represents the strain.

Thermal strain:

$$\varepsilon_{th} = \alpha(T - T_{ref})$$

Here α is the coefficient of thermal expansion, T is temperature (Kelvin), and $T_{ref}$ is the strain-free reference temperature (also Kelvin).

## 2. DESIGN

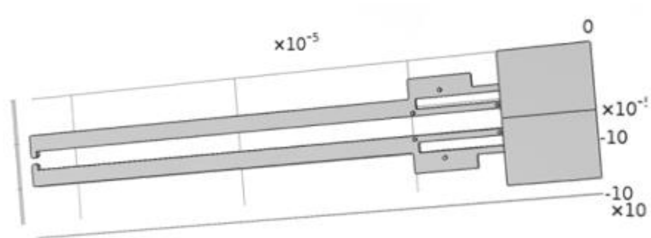


Figure 1. Schematic of the gripper model, showing hot arm and cold arm which is wider in height.

### A. *Gripper Dimensions.*

The structure shown in Figure 1 is having heater and gripper arm. The structure length to anchor length ratio is taken into consideration. The cold arm is shorter than hot arm. An air gap is considered in between two arms with initial air gap. All the dimensions are relatives in values. Global definition is specified in the form of table parameters, Micro meter dimensions are maintained for structure width, Length, and thickness. Voltage applied will be a variable DV. Table 1 Shows the summary of the dimensions.

TABLE I. DIMENSIONS OF THE GRIPPER STRUCTURE.

| | |
|---|---|
| Heat transfer coefficient of su8 of thickness 20 um htc_s | 0.04[W/(m*K)]/20[um] |
| HTC of upper surface with length of 550 um | 0.04[W/(m*K)]/550 |
| Applied Voltage DV | 10[V] |

| | |
|---|---|
| Height of Hot Arm d | 7[um] |
| Height of Cold arm dw | 14.5[um] |
| Gap between arms gap | 7[um] |
| Difference in length between hot arms wv | 11[um] |
| Actuator Length L | 450[um] |
| Length of longest hot arm L1 | L-wb |
| width of Gripper fixed base wb | 100[um] |
| Length of Shortest hot arm L2 | L-wb-wv |
| length of cold arm thick part L3 | L-2*wb-wv-L/48-L/6 |
| length of cold arm thin part L4 | L/6 |
| L5 tip | L/48 |
| Height of flexure connecting rectangle d1 | d+hapx_st1 |
| Height of flexure connecting rectangle d2 | d+hapx_st2 |
| Length Of Tip LT | L/5 |
| Tip to Tip Air Gap TGP | 7[um] |

### *B.* ***Top*** **Layer.**

The structure with relative dimension is placed on the top of the substrate. One side consists of electric potential node and other side of ground, rest of the area is the electrical insulation. Interior boundaries are cleaned to form rectangle areas. 1/3 of the roller diameter is used to round off the edges. This is interference drag when mechanical parts exposes to air in aerodynamics, fillets distribute the stress concentration over a wider area and mechanical parts will be more durable and capable of bearing larger loads. The distance between structure geometry to substrate is 2 micrometer, so that arm structure and anchor structured are separately, The structure before extrude is shown in Figure 2

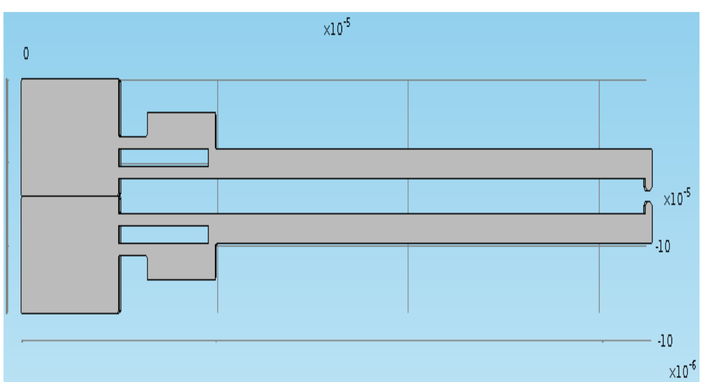


Figure 2. Top layer of Arm structure before extrude

### *C.* ***Anchors and rollers***

One anchor and 3 rollers are placed so that the device will not displace in upward direction circle for rollers and rectangles for anchor is made respectively. The distance between rollers are 2 micro meter length. While extruding the work plane was selected as reverse direction so that plane will be on bottom of the arm structure. Figure 3 shows the structure after extrude.

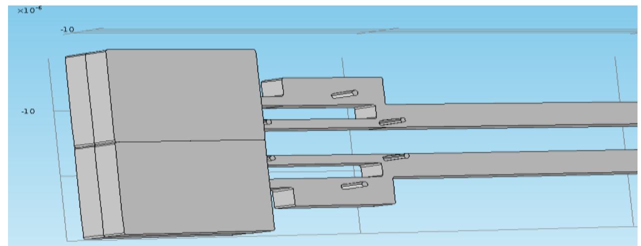

Figure 3. Showing the anchors and rollers after extrude

Constant temperature is assigned to bottom of boundary so is explicitly defined. Bottom boundary is substrate contact.. This is defined with geometric entity level of bottom anchors and rollers as selected boundary.

## 3. MATERIAL

Major three categories of polymers are ,Plastics, fibers and elastomers. incorporating polymers include 1) Polymer material provides greater mechanical yield strain than Silicon, Silicon is a mechanically strong material with a large Young's modulus but it is relatively brittle.[3]. Elastomers, can sustain greater degree of deformation used for smart skins and flow sensing.[4]. 2) To acquire polymer materials it is significantly lower cost. Processing need not require clean room confinement resulting lowering the cost of fabrication. 3) silicon substrates comes with wafer format but Polymer substrate can be in non wafer forms 4) Polymer attracted electronics and optoelectronics like transistors, displays, photo voltaic devices, memory, and Sensors and actuators made by polymer MEMS will fully integrated with electronics in like material systems. 5) Tool box for silicon micromachining is limited. Polymer MEMS with casting and molding are new fabrication process with low temperature chemical vapor deposition. embossing. Spraying, screen printing, thick film processing and stereo lithography. ]6) Polymers has unique chemical, structure and biological functionalities not available in any other material systems , due to environmental pH and temperature changes functional hydrogels can vary their volume. Energetic ion track etching can make poly carbonate films holes with controlled nanoscopic dimensions.

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The property of mechanical strength and material deformation under the electrical excitation is reported.[5] The material property tables is as shown in Table 2

TABLE II. POLY SILICON MATERIAL PROPERTY TABLE

| PROPERTIES | EXPRESSION |
|---|---|
| Coefficient of thermal expansion (alpha) | 2.6-6 1/K |
| Heat capacity at constant pressure (cp) | 678[j/(kg *K)] |
| Relative permittivity (epsilon) | 4.5 |
| Density | 2320[Kg/m3] |
| Thermal conductivity (K) | 34[W/(m*K) |
| Electrical conductivity (Sigma) | 5 4 S/m |
| Young's modulus (E) | 160 9 [pa] |
| Poisson's ratio (nu) | 0.22 |

## 4. MODELING

### D. *Joule Heat transfer boundary conditions*

The substrate consists of anchor on which device is placed and there are three rollers to avoid upward movement. Anchor and rollers temperature area kept same as substrate and it is 253.15 K remaining parts of the boundaries interact thermally with air as surrounding. The heat is made to flow by heat flux. The heat transfer coefficient is the thermal conductivity of air divided by the distance to the surrounding surface for the system. Two heat flux conditions are specified heat flux 1 boundary condition applies to all boundaries except the top-surface boundary and those in contact with the substrate. A Temperature condition on the substrate contact boundaries will override this Heat Flux condition, so one do not explicitly need to exclude those boundaries. In contrast, because the Heat Flux boundary condition is additive, it must explicitly exclude the top-surface boundary from the selection. Here in Inner heat flux definition globally defined as htc_s is used. on heat flux on the surface globally defined as htc_us is used

Heat Flux = Heat transfer coefficient x ( temperature - normal temperature)

### E. *Design assumption*

This material is applied to all geometric entity level domains first, Then silver is applied for heater boundaries. This is added from the material browser.

### F. *Heat Transfer process.*

Equations of thermal expansion and joule heating will dominate the heat transfer process.[6] Fixed constrains option is used for bottom of the anchors. During thermal expansion the gripper arm will move upwards so a roller under solid mechanics is used to only in x -y direction. Heat Flux is applied on bottom surface boundary with constant inward heat flux value is

$$q_0 = h * (T_{ext}-T)$$

where coefficient h is 0.04[W/(m*K)]/20[um] . This is applied to all the boundary then bottom part is excluded another heat flux equation is applied a for upper surface i.e 0.04[W/(m*K)]/550[um] here external temperature is 293.15 K.

### D. *Physical conditions equations.*

A name for substrate contact is assigned to keep normal temperature of 293,15K. Thermal linear elastic applied all to the boundary as isotropic. Thermal expansion coefficient defined equations are applied, thermal expansion alpha , Strain reference temperature as normal temp of 293.15K from material property is applied as defined in Table 2. Electrical conductivity, electric field, relative permittivity , thermal conductivity K, Heat capacity at constant pressure are applied for material. Electromagnetic Heat source is applied to all domain, except anchors and free moving rollers.[7] Thermal insulation is included in boundary between planes of two geometry

### E. *Electric Potential.*

Zero volts is assigned as ground point and opposite node is used as electric node whose voltage assigned as 10 V.

## 5. MESHING

Under the finite element analysis meshing is done on the structure for finer distribution.. Free Triangular is chosen for substrate contact boundary as its shape is rectangular. Number of elements distributed as 2 , free triangular is used for other boundaries. The meshing values and shapes is as shown in fig 4.

TABLE III. MESH SIZES AND VALUES.

| Name | Value |
|---|---|
| Maximum element size | 5.2E-5 |
| Minimum element size | 6.5E-6 |
| Resolution of curvature | 0.5 |
| Resolution of narrow regions | 0.6 |
| Maximum element growth rate | 1.45 |
| Predefined size | Fine |

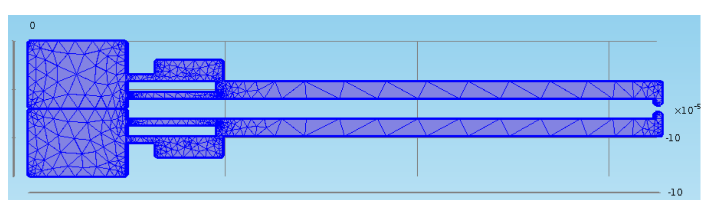

Figure 4. Meshing of the structure.

## 6. RESULTS

Fig 5 Shows the gripper tip thermal expansion. Tip is expanded up to 20 um for application of 10 v. Effect on material stress at heating element is studied . It is observed a spike of stress appears at the heater element as shown fig 6. Heat flux due to conductivity at the heater node is probed. It surges at the junction as shown in fig 7

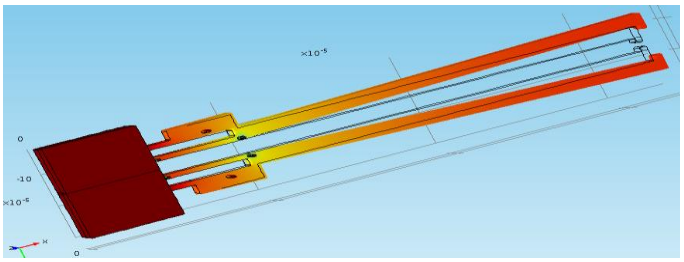

fig 5. Thermal expansion

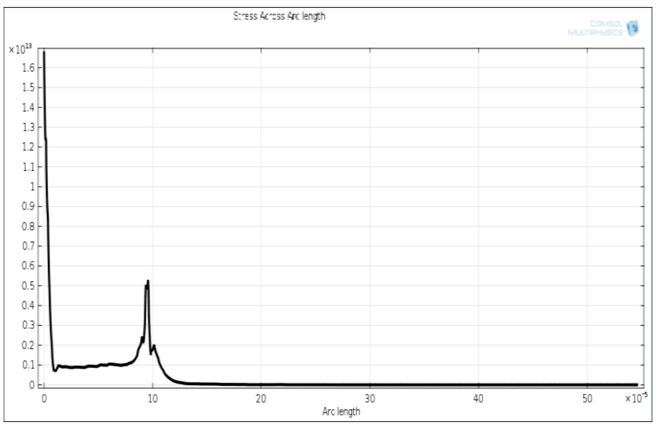


Fig 6. Stress at the heater node..

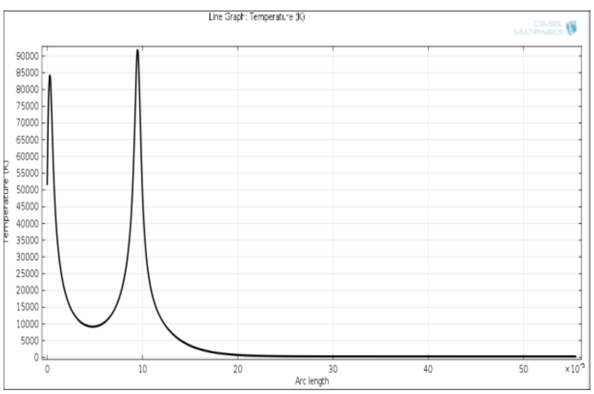


Fig 7. conductivity heat flux across the arm length.

As the electric potential applied the arm displacement occurs linearly except small jerk at heater junction position of the gripper as shown in fig.8

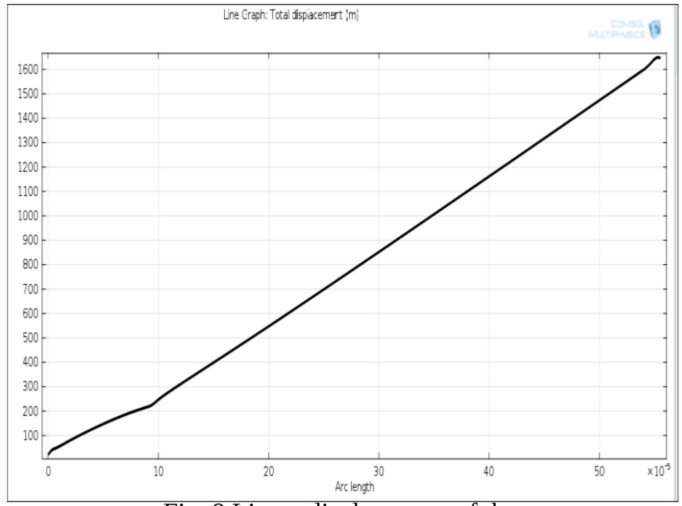


Fig. 8 Linear displacement of the arm.

## 7. CONCLUTION

Su8 based electro thermally actuated micro gripper with actuators has been designed. a proper potential is optimized to get a increased displacement at the tip. When the size of the arms and tweezers are increased the displacement increases. The shape of the cold arm also affects the displacement. The electric potential need to applied as electric potential increases the structure deformation. By using different materials and dimensions Further improvements can be realized.

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