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# Design and Analysis of Micro-tweezers with Alumina as gripper using COMSOL Multiphysics

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**Abstract:** Micro-tweezers have been widely investigated because of their extensive applications in micro-fluidics technology, microsurgery and tissue-engineering. It has been reported that thermal actuation provides greater forces and easier control when compared to electrostatic micro actuation. Conventional micro tweezers for micromanipulation are made of silicon. But when silicon is subjected to high compression force, it becomes too fragile, smoother and exhibits poor adherence. An alternative material is aluminum-oxide (alumina $Al_2O_3$), which has good mechanical strength and low chemical reactivity. In this paper, we discuss about the effects of Alumina as gripper on the operation of micro-tweezers. The geometric optimization for the micro-tweezers was performed by simulating a wide range of possible geometries using COMSOL Multiphysics, a commercial Finite Element Analysis (FEA) package. We have presented simulated results for different applied voltages ranging from 1 V to 15 V with the corresponding stress, current density and temperature profile. For an applied voltage in the range of 1 V to 15 V, it is found that the temperature of the micro-tweezers varies from 300 ° K to 1000 °K. Micro-tweezers with Alumina gripper are found to have uniform stress distribution ranging from 0.1 GPa to 0.3 GPa in silicon with maximum stress of 1.7GPa on Alumina gripper. Comparatively, micro tweezers with pure silicon have a non-uniform stress distribution and maximum stress of 0.27GPa on the gripper. We found that the displacement of the gripper with the applied voltage is higher in the case of Alumina gripper than the silicon grippers.

**Keywords:** ETC, Micro-tweezers, COMSOL, aluminum-oxide, stress.

## 1. Introduction

The advance of miniaturization technology has led to the development of micro-tools which are suitable for precisely manipulating objects at small scales. Applications exist in biomedical and biological fields [1], micro-assembly of microelectronics, communication devices and precision machining. There is a great demand for micro-grippers or micro-tweezers with a controlled grasping force and accuracy. Such devices must be easy to operate with a large opening displacement at low temperature and low power consumption .The driving mechanism used in micro-tweezers is electro-thermal actuation [2]. In recent years, thermal actuation in micro-electromechanical systems (MEMS) has received considerable attention. When compared to the widely-used electrostatic micro actuation, thermal actuation provides larger forces and is also easier to control. Micro-tweezers based on electro-thermal actuators need a high current and are usually operated at high temperature [3], they are able to deliver a large force with large opening displacements, and are, therefore, one of the preferred driving mechanisms for micro-tweezers, especially for non-biological applications.

The electro-thermal actuator, also called a heatuator [4], takes advantage of the shape to create "bi-metallic" effect using a single material as shown in Figure 1(a). When current is passed through the folded-beam structure from one mechanically-anchored electrode to the other, the narrow portion gets hotter than the wide portion because of higher current density and the ensuing larger Joule heating. Therefore, the narrow arms tend to expand more than the wide arms, and they achieve thermo-elastic equilibrium by bending toward the wide arms. A modification to the heatuator is shown in Figure 1 (b). As shown here, if we pass current through the narrow and wide arms in parallel rather than in series, the structure will then bend towards the narrow arm. This is because the resistance of the wide arm is smaller and hence draws larger current and gets hotter than the narrow arm. This parallel connection gives rise to new ways of achieving the selective heating of a flexible continuum, and leads to the concept of embedded electro-thermal-compliant (ETC) actuation.

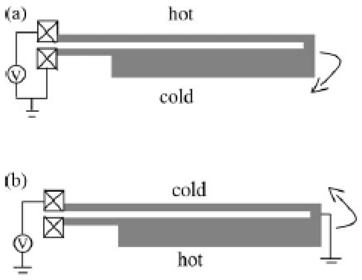

**Figure 1**. (a) Series arrangement of basic electro-thermal actuator; (b) parallel arrangement [4]

## 2. Device Design

In our design, the micro-tweezer has a total arm length, $L_T$ of 580µm, with an initial tip opening of 15 $\mu$m. This design is based on the lateral thermal actuator proposed by Guckel *et al* [2].

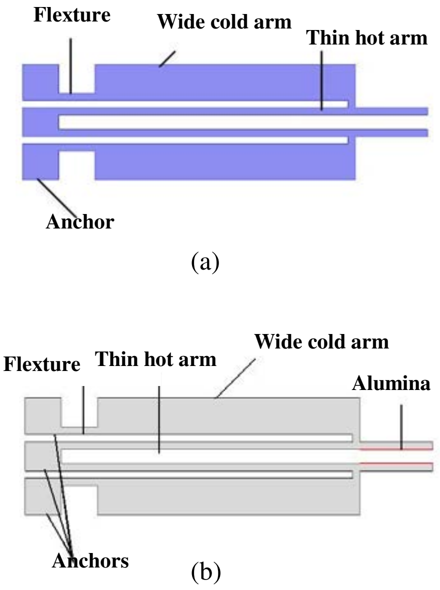

**Figure 2** Structure of the micro-tweezers (a) Silicon gripper (b) Alumina gripper

Figure 2 shows the structure of our micro thermal actuators with (a) the silicon structure with silicon gripper and (b) silicon structure with Alumina gripper. It consists of a pair of lateral thermal actuators with hot arms facing each other. Each heatuator has a thin hot arm, a wide cold arm and a hinge. When current passes from one terminal to the other, the thin (high electrical resistance) arm gets heated more than the wide (low electrical resistance) cold arm. The differential temperature between the hot and cold arms leads to a net expansion of the hot arm, generating a lateral deflection. The deflection of the heatuator is affected significantly by the widths of the hinge and the hot arm, and the gap between the hot and cold arms [5, 6]. A smaller gap and a narrower beam lead to a larger deflection. In our design, we have taken the properties of silicon similar to [4].

Generally ceramics are the right material to use at high temperatures and to get good grip in the tweezers. Alumina is the strongest and stiffest of the oxide ceramics. Its high hardness, excellent dielectric properties, refractoriness and good thermal properties make it the material of choice for a wide range of applications [7]. The melting point of silicon is found to be 1414 °C and that for alumina is 2072 °C. In this paper, we propose to use the Alumina at the gripper ends as shown in Figure 2 (b). The properties of Alumina are mentioned in Table 1.

**Table 1:** Properties of Alumina used in simulation

| Properties of Alumina | Values used | Units of measure |
|---|---|---|
| Elastic Modulus | 300 | GPa |
| Poisson's ratio | 0.21 | |
| Thermal Conductivity | 18 | W/m•°K |
| Coefficient of Thermal Expansion | 8.1 | $10^{-6}$/°C |
| Volume Resistivity | $>10^{14}$ | Ohm-cm |

## 3. Simulation with FEA

In order to analyze the behavior of the above two structures using COMSOL multi physics, we have applied the parametric sweep for the voltage varying from 1 V to 15 V and measured the temperature, current density, deformation and stress with the displacement of the arms. Hence, the simulation has been carried out for the voltage of up to 15 V in which the temperature obtained is less than 1000 °C. The results are discussed in the next successive subsections.

## 4. Results and Discussion

### 4.1 Current Density and temperature:

Figure 3 shows the snap shot of the maximum current density of the device with an applied voltage of 6 V. This shows that the current flow is maximum in the narrow arm and moderately less in wide arm. This will tend to make the narrow arm hotter than the wide arm. So, the structure tends to move along the wide arm. The maximum current density of the structure for 6V is 4.5611 x $10^7$ A/$m^2$.

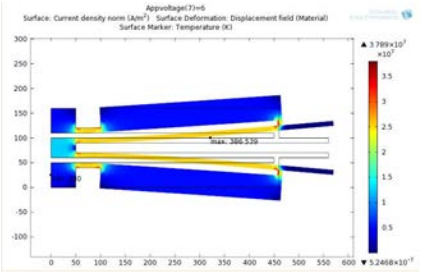

**Figure 3**. Current density of the device for an applied voltage of 6 V

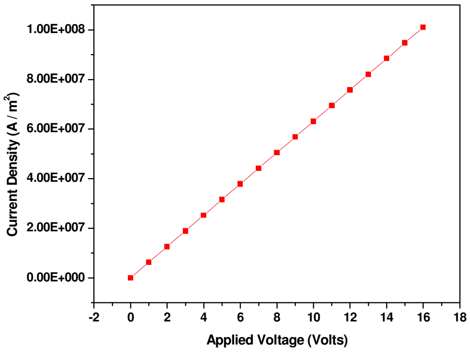

**Figure 4.** Current Density Vs. Applied Voltage(V)

The maximum current density of the devices for the applied voltage of 0 V to 15 V increase linearly in both the device structures with Silicon gripper and Alumina gripper and they are the same. The graph showing the linear increase of maximum current density with applied voltage is as shown in Figure 4.

Similarly, the Figure 5 illustrates the temperature distribution across the structure and the temperature is the same in both the Silicon gripper and Alumina gripper structures. The maximum temperature is obtained at the narrow arms and the minimum temperature at the anchors. The maximum and minimum temperature for the applied voltage of 10V is found to be 300 °K and 540 °K respectively.

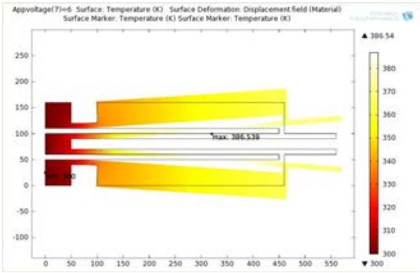

**Figure 5**. Temperature across the device for the applied voltage of 16V

For the voltage range of 0 - 15V, maximum temperature of the device is plotted against the applied voltage as illustrated in the Figure 6. The graph is the exponential curve as the temperature is directly proportional to the square of the applied voltage and the plot is well matching with the earlier reports [8].

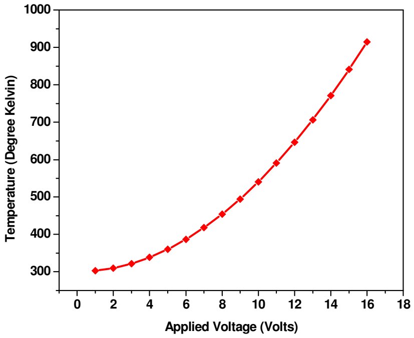

**Figure 6.** Maximum temperature versus the applied Voltage

## 4.2 Stress and Displacement:

Figure 7 shows the stress distribution on the silicon gripper structure for an applied voltage of 6 V. The stress is varying throughout the length of the hot and cold arms and the maximum stress occurs at the centre of the hot arm. This may easily collapse the structure at the high temperatures.

Figure 8 shows the stress distribution on the Alumina gripper structure for the applied voltage of 6 V and we found that the stress is almost uniform in the silicon hot and cold arms. The maximum stress occurs at the Alumina gripper region and not at the centre of the hot arm. This will make the structure less brittle and can yield a maximum displacement. Figure 9 shows the increase in the maximum stress with the increase in applied voltage for both the silicon gripper and Alumina gripper. The stress obtained in the Alumina gripper is higher than silicon and the Alumina is the hardest material which can withstand the higher stress without any damage to the structure.

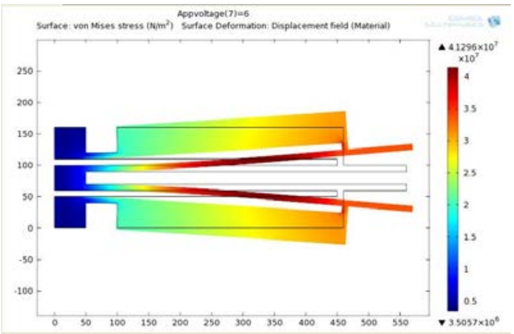

**Figure 7** Stress of the silicon gripper for an applied voltage of 6 V

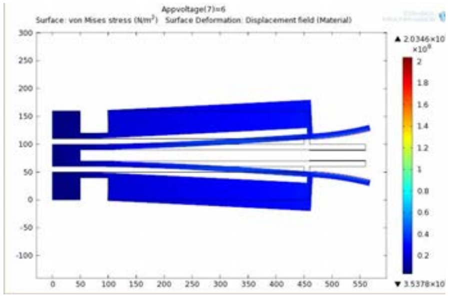

**Figure 8** Stress of the Alumina gripper for an applied voltage of 6 V

Figure 10 shows the increase in the displacement of the upper arm measured with respect to its original position with the increase in applied voltage for both the structures. We observe that the devices are showing the linear range of operation only at low voltages. It is observed from the data that the plastic deformation of the hot arm occurs above 1V and 1.25 V for Alumina and Silicon grippers respectively. In the plastic region, the additional input voltage does not lead to additional displacement. Figure 11 shows to focus on the increase in the displacement at the low input voltage range of 0 V to 2 V.

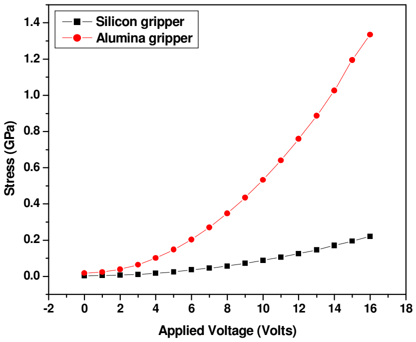

**Figure 9** Stress at the tip of the Silicon and Alumina grippers

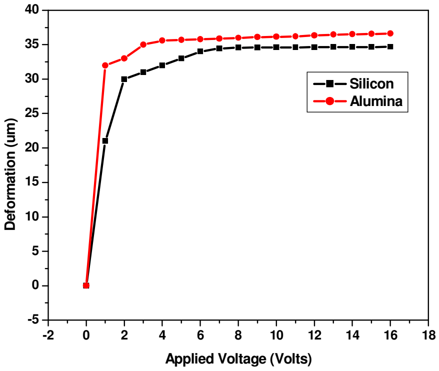

**Figure 10** Displacement of Silicon and Alumina grippers with the applied voltages

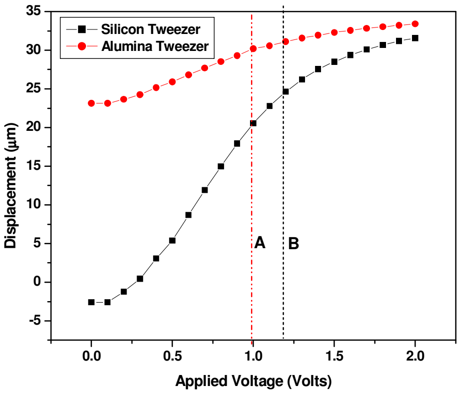

**Figure 11** Deformation of Silicon and Alumina grippers at low voltages

We can see that the Alumina gripper structure gives more displacement with the applied voltage but it reaches the plastic region earlier than the silicon gripper structure. Also, we found that the Alumina gripper structure shows the displacement of 23.13 µm even when no voltage is applied. This might be due to excessive residual stress developed at the Alumina gripper tip which is in the order of GPa. We can also observe that the Alumina gripper bends in the outward direction in a curved fashion due to stress as shown in Figure 12.

## 5. Conclusion

A comprehensive thermal model of micro-tweezers is designed and simulated using COMSOL 4.2. The results show the variation of current density and temperature across the structure for the applied voltage are the same for both the types of structures. We also observed that maximum temperature and maximum current density increase linearly with the applied voltage. Though the Micro-tweezers with Alumina grippers at the tips show higher displacement than the silicon grippers, the useful linear range of operation is less. Though the stress at the centre of the hot arm when we use Alumina gripper is the same as that of the silicon structure, the stress at the Alumina gripper tip is very high and it increases with the voltage. During fabrication, the deposition of Alumina can be done by thermal evaporation of Aluminium in the oxygen ambience. But obtaining the Alumina in the lateral sides of the gripper tips is difficult to realize. The structure has to be modified with the Alumina for higher thermal operation and to have a good grip and at the same time to overcome the fabrication difficulties and to reduce the stress compared with silicon grippers.

## 7. References

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