DESIGN, SIMULATION AND ANALYSIS OF A THERMALLY DRIVEN MICRO-TWEEZERS

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ABSTRACT

A thermal bimorph actuator based micro tweezers with four different configurations are designed, modelled, fabricated and tested. In this paper, we present the modelling of mechanical, electrical, geometrical characteristics and testing of thermal bimorph micro tweezers. 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. The mechanical motion is improved by changing the geometrical dimension of the device. It was found that one of the device, having longer arm is capable of picking up larger objects and other device, which has gripper in its centre is capable of picking up objects of smaller dimensions.
Keywords: Micro-tweezers, Micro-Gripper, MEMS, CAD

1. INTRODUCTION

The advance of miniaturization technology has led to the development of micro-tools which are suitable for micro level manipulation of objects. Such micro-tools find application in biological and chemical field. One such micro-tool is the micro-gripper or the micro-tweezers with a controlled grasping force and accuracy [1-3]. 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. In recent years, thermal actuation in has received considerable attention in the several fields. 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, they are able to deliver a large force with large opening displacements, and are, therefore, one of the most preferred driving mechanisms for micro-tweezers, especially for non-biological applications [4-7].

The electro-thermal actuator, also called a heat actuator, 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 heat actuator 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 (E-ETC) actuation [8-10].

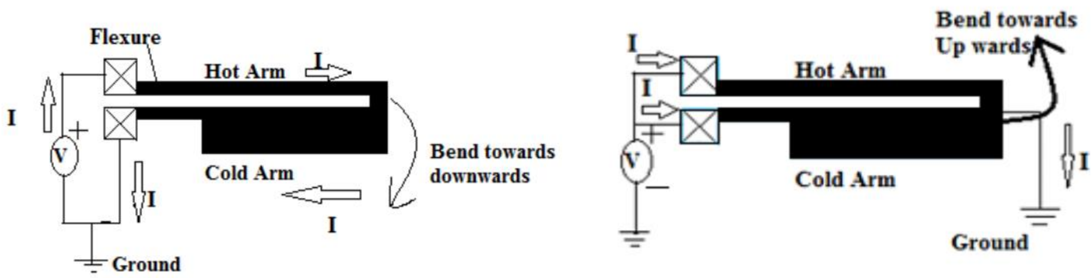

Figure 1: (a) Series arrangement of basic electro-thermal actuator; **(b)** parallel arrangement

2. DESIGN CONCEPT

We have designed four different types of micro thermal actuators to perform micro gripping. The total length of all micro tweezers varies from 900 µm to 1455 µm. Each heat actuator has a thin hot arm, a wide cold arm and a flexure. When current passes from one terminal to the other, the thin (high electrical resistance) arm heats 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 heat actuator is affected significantly by the widths of the flexure and the hot arm, and the gap between the hot and cold arms. The device D1 is designed, with hot arm width 900µm and the flexure 150µm; spacing between the hot arms is 20µm. The device D2 is designed, with hot arm width 900µm and the flexure 100µm, spacing between the hot arms 20µm. To improve the gripping ability of micro tweezers, this device is designed with micro grippers, the size of gripper is 10x5µm. The device D3 is designed, with hot arm width 1455µm and the flexure 150µm, spacing between the hot arms 20µm. The micro grippers, of size 10x5µm, are placed at the centre of hot arm. This device is used for gripping objects of very small dimensions. The device D4 is designed, with hot arm width 1100µm and the flexure 100µm, spacing between the hot arms 20µm, and micro grippers of size 10x5µm.

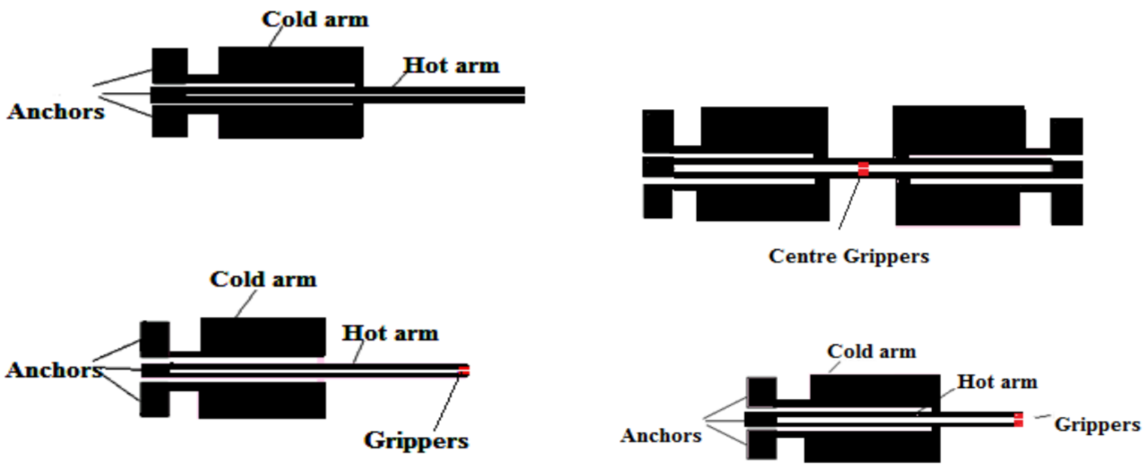

Figure 2: Various Schematic drawings of thermal bimorph Micro tweezers

When voltage is applied to the micro tweezers, the current passes through the hot beams, thereby thermal expansion of these beams leads to an upward deflection. The deflection of micro tweezers depends on the length of hot arm as well as the length of flexure length. The larger the flexure length, the larger the deflection of the structures. The flexures length provides flexibility in movements for the tweezers arms. All devices can withstand high current without suffering high temperature deformations.

Table 1: Geometric dimension of Devices

Component	Device 1		Device 2		Device 3		Device 4	
	Width (μm)	Height (μm)	Width (μm)	Height (μm)	Width (μm)	Height (μm)	Width (μm)	Height (μm)
Anchors (Top to Bottom)								
1	152	152	152	152	140	112	152	152
2	160	40	160	40	160	70	160	40
3	152	152	152	152	140	112	152	152
Cold Arm	400	100	300	80	400	100	300	80
Spacing between Cold Arms	-	-	-	-	355	-	-	-
Hot Arms	900	10	900	10	1455	10	1100	10
Spacing between Hot Arms	-	20	-	20	-	50	-	20
Spacing between Hot and Cold Arms	-	-	-	12	-	12	-	12
Flexure	150	10	100	10	150	10	100	10
Gripper	-	12	10	5	10	20	10	5
Spacing between Grippers	-	-	-	10	-	10	-	10
Connector	10	12	10	12	10	12	10	12

4. RESULTS AND DISCUSSION

4.1 Current Density and temperature:

Figure 3(a) 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.

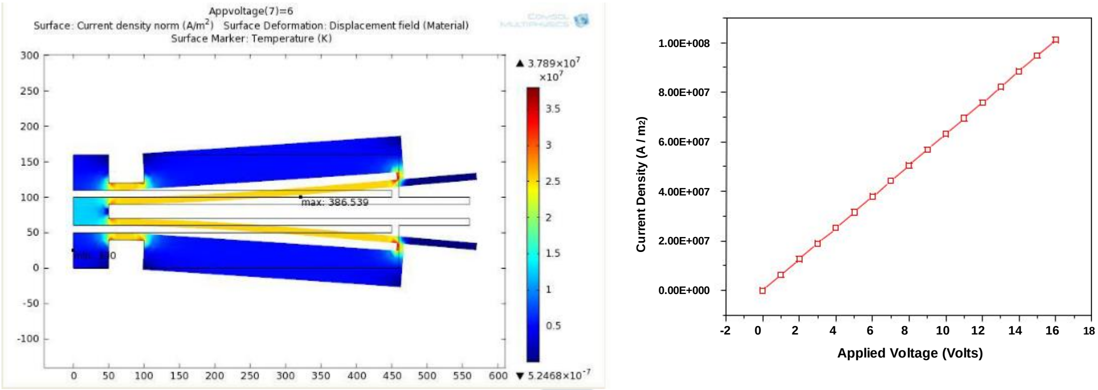

Figure 3: (a) Current Density of the Device for applied voltage of 6V **(b)** Current Density v/s applied voltage

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 3(b).

Similarly, the Figure 4(a) 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.

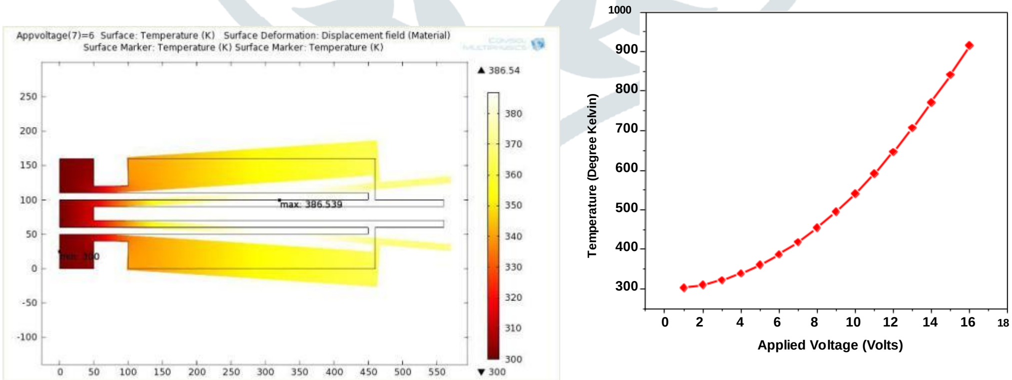

Figure 4: (a) Temperature across the device for applied voltage of 16V **(b)** Maximum Temperature v/s applied voltage

For the voltage range of 0 - 15V, maximum temperature of the device is plotted against the applied voltage as illustrated in the Figure 4(b). The graph is the exponential curve as the temperature is directly proportional to the square of the applied voltage.

4.2 Stress and Displacement:

Figure 5 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 center of the hot arm. This may easily collapse the structure at the high temperatures.

Figure 5 also 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 center of the hot arm. This will make the structure less brittle and can yield a maximum displacement.

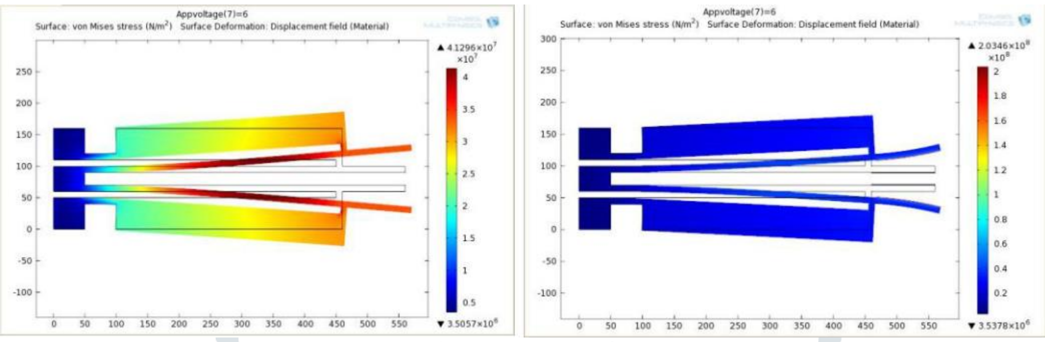

Figure 5: Stress of Silicon and Alumina Gripper for applied voltage of 6V

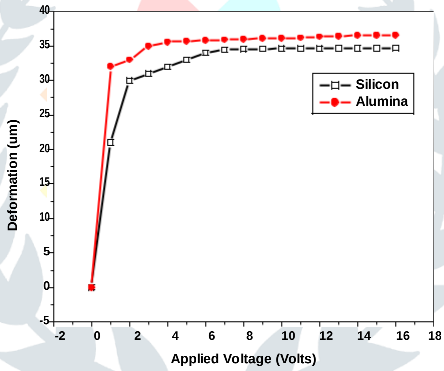

Figure 6: Displacement of Silicon and Alumina Grippers with the applied voltages

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.

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. The stress at the center 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 Aluminum in the oxygen ambience. From the results it was clear that the devices D1 and D4 showed a good displacement at minimum applied voltage. As the arm length increases the deflection of the arm increases. The device D3 which is a different structure was capable of holding objects of very small dimensions at very low applied voltage. The testing results of micro tweezers are compared with Finite Element Analysis [FEA] results which show good repeatability and reliability even when the device subjected to high voltage short pulses.

6. REFERENCES

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