A Parametric Study on Electrothermally Actuated Compliant Microgripper

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Abstract: At the Micron-level, Thermal Actuation exerts larger forces compared to the widely-used electrostatic actuation. To obtain large displacements at low voltage the principle of Electro Thermal actuation is used. It works on the principle of selective non-uniform Joule heating which results in thermal expansion due to constraints. The Microgripper presented here is studied and analyzed by carrying out design parameterization by varying thickness and Applied Voltage.
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Keywords: Electro Thermal Actuation, Joule Heating, Compliant Micro Gripper.

1. Introduction

Microgripper has widespread applications in the areas of micro robotics, microsurgery, micro-fluidics, micro relays, assembling and miniaturized medical instrumentation. Actuation principle involved may be electro thermal, electrostatic, piezoelectric, shape memory or electromagnetic. 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 [1]. Differential expansion of a laminate made of two materials of unequal thermal expansion coefficients, the bi-metallic or bimorph effect [2], is well known. This has been used effectively in MEMS to generate large forces [3-6]. External heating or internal Joule heating causes elastic structures to expand. If constrained mechanically, these structures will generate forces making them suitable for actuation. Such actuators were also reported in the literature [1,7-12]. The electro-thermal actuator, also called a heatuator, [8] takes advantage of the shape to create ``bi-metallic" effect using a single material as shown in Fig. 1a. 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 arm tends to expand more than the wide arm, and they achieve thermo-elastic equilibrium by bending toward the wide arm. The modification to the heatuator is shown in Fig. 1b. 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.

$$R = \frac{\rho l}{A}$$

Where, R= Resistivity
l =Length
A =Area
This is because the resistance of the wider arm is lesser hence requires larger current and gets hotter than the narrow arm.

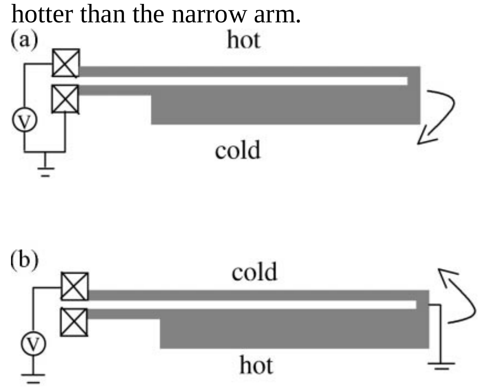

Figure 1 (a) Series arrangement of the basic electro-thermal actuator [1]
(b) Parallel arrangement [2].

Figure 1 shows series and parallel arrangement of the electro thermal actuator which is modified to be a gripper and analysed in the present work.

2. Modeling the Microgripper

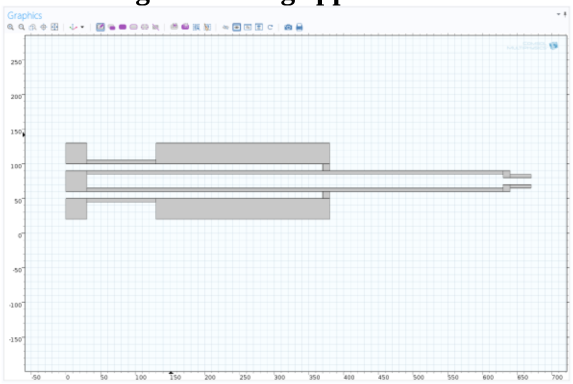

Figure 2 Microgripper Modelled in COMSOL Multiphysics 4.4

Microgripper was modelled with appropriate dimensions and is as shown in figure 2. [13]
The Equivalent models namely, Thermal, elastic and Electrical models for the Microgripper can be written and represented as shown in the figures 3, 4 5 respectively.[14]

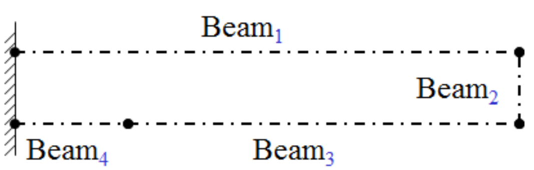

Figure 3 Equivalent Elastic Model

Where, beams 1,2,3,4 are the beams with different stiffness $K_1K_2K_3K_4$ respectively.

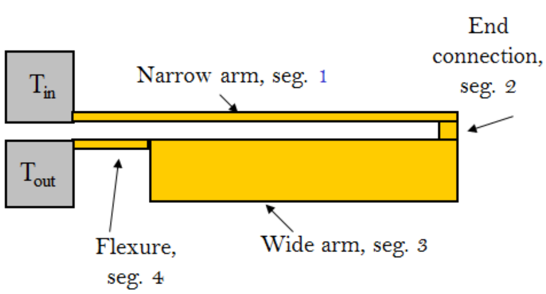

Figure 4 Thermo elastic Model

Heat input is given using DC power supply, through T_{in} as shown in figure 4, the supplied heat increases the temperature of narrow arm and tends to expand more than the wider arm. Presence of flexure makes the structure bend towards a particular side.

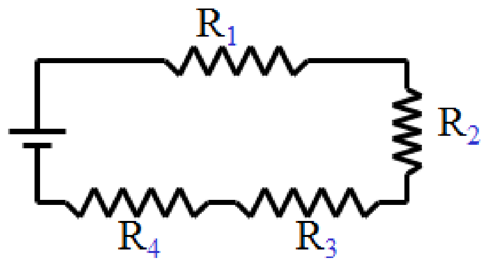

Figure 5 Electrical model.

The electrical model can be written by replacing the stiffness of the beam with resistances R1, R2, R3, and R4 respectively.

3. Finite Element Analysis

The Microgripper is designed and simulated in COMSOL Multiphysics 4.4 According to the principle discussed in introduction section, the narrow arm gets expanded more than the wider arm as shown in figure 6. A maximum temperature of 919 K was observed due to the selective heating of the different parts of the gripper. A displacement of 34.3 µm was seen for the gripper having thickness 5µm and supplied with a voltage of 7v and is as shown in figure 7

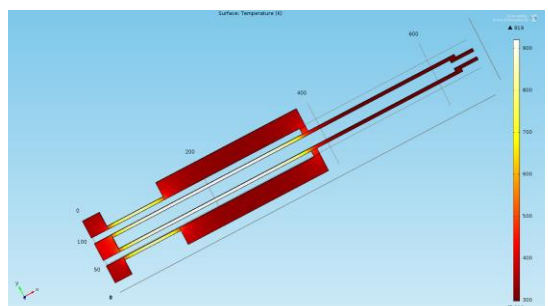

Figure 6 Temperature Distribution.

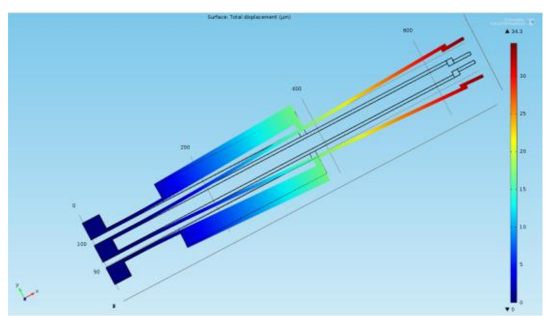

Figure 7 Maximum Displacement obtained

4. Use of COMSOL Multiphysics® Software

COMSOL Multiphysics 4.4 was effectively used to simulate the real time experiment conducted on the Microgripper which was cut using Micro wire cut EDM machining. Microgripper was actuated using a Variable DC power supply, The Temperature was measured by an Inferred Thermometer and the displacement of the arms of the gripper were recorded using portable microscope which was connected to Computer system.

The physics Solid Mechanics from Structural Mechanics, Electric Currents (ec), from the module AC/DC, Heat transfer in solids from the module Heat Transfer were chosen to accomplish the task of creating the Experimental Environment.

5. Parameterization

Parametric sweep was carried out in COMSOL Multiphysics 4.4, to study and analyze the effect of different parameters on the performance of the gripper.

Initially, by selecting a Biocompatible material (Ti beta 21S) as the material of gripper the applied voltage was varied starting from 1V to 8V. Then the material was changed to one more biocompatible material called Structural Steel and the analysis was carried out. It was found that the displacement went on increasing upon increasing voltage. The plot of Applied Voltage v/s Displacement is as shown in the figure 8.

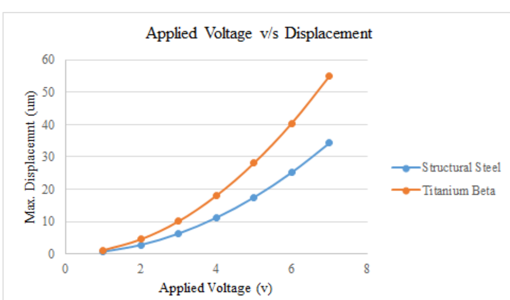

Figure 8 Applied Voltage v/s Displacement for the two biocompatible metals.

The Thickness of the Microgripper was varied from 5µm to 100µm and studied for the performance of the Microgripper. It was observed that, the displacement rapidly increased when the thickness was increased initially and after the optimum thickness of 40 µm, there was no remarkable increase in the displacement characteristics. From this, it can be concluded that, the thickness of the gripper has an effect on the displacement characteristics of the arms of the Microgripper only up to the threshold thickness of 40 µm. The effect of the thickness on displacement of the Microgripper is as shown in the figure 9.

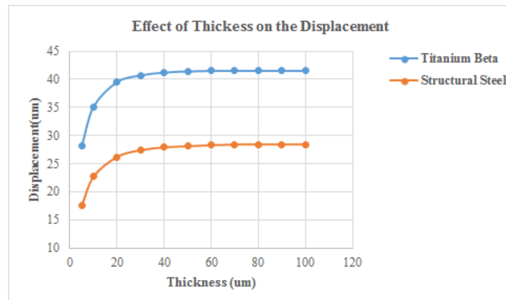

Figure 9 Effect of the thickness on displacement of the Microgripper

The reason for the above observation may be due to the selective heating of the parts of the gripper. The Joule heating is more prominent when the surface to volume ratio is less. When the thickness is increased, then the surface to volume ratio increases and the Joule heating becomes less pronounced.

6. Conclusions

The Microgripper was studied for its performance analysis in COMSOL Multiphysics 4.4 by Electrothermal method actuation. The Physics selected for the analysis in simulating the experimental environment were Solid Mechanics from Structural Mechanics, Electric Currents (ec), from the module AC/DC, Heat transfer in solids from the module Heat Transfer were chosen to accomplish the task of creating the Experimental Environment.

Parametric sweep was carried out in COMSOL Multiphysics 4.4, to study and analyze the effect of different parameters on the performance of the gripper.

Initially, the applied voltage for the Microgripper was varied starting from 1V to 8V and the displacement of the gripper was studied. There was an exponential increase in the displacement with the increase in voltage.

The Thickness of the Microgripper was varied from 5µm to 100µm and studied for the performance of the Microgripper. It was observed that, the displacement rapidly increased when the thickness was increased initially and after the optimum thickness of 40 µm, there was no remarkable increase in the displacement characteristics.

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