Analysis & Design Optimization of laterally driven Poly-Silicon Electro-thermal Micro-gripper for Micro-objects Manipulation

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Abstract: A 3-D MEMS electrothermal microgripper has been designed and simulated using COMSOL 4.2a. Electrothermal mechanism is the most widely used mechanism for providing large displacements at low voltage. The gripper presented here is geometrically optimized to explore the effect of dimensional variation on its performance. Length of the hot arm and gap between the hot and cold arm is varied.

Keywords: MEMS, Electrothermal Actuator, Joule Heat, Thermal Expansion.

1. Introduction

Micro-grippers find applications in micro-robotics, microsurgery, micro-fluidics, micro-relays, assembling and miniature medical instrumentation. Actuation principle involved may be electrothermal, electrostatic, piezoelectric, shape memory and electromagnetic. It has been found that thermal actuation provides greater displacement at low voltages when compared to other mechanisms. Micro-gripper is comprised of two microactuators (hot-and-cold-arm actuator) which operates on the basis of Joule heating and thermal expansion. The hot-and-cold arm actuator consists of one narrow (hot) arm, one wide (cold) arm and the flexure. Flexure joins the wider arm with the anchor as shown in figure 1. When voltage is applied in series to this structure, the current will flow through these arms with same heat distribution. Thus the narrower arm gets more heated due to small resistance according to the relations; $R=\rho L/A$ and $H=I^2R$, where R is the resistance, L is the length and A is the area of cross section of the arm, H is the Joule heat produced in the arm and I is the current flowing through the arm. As a result of more heated narrower arm, it will deflect more than wider arm. Thus, the narrower arm creates mechanical force and pushes the structure in direction narrower to wider arm as shown in figure 1. Also, when the voltage is applied in parallel, then the structure bends in opposite direction

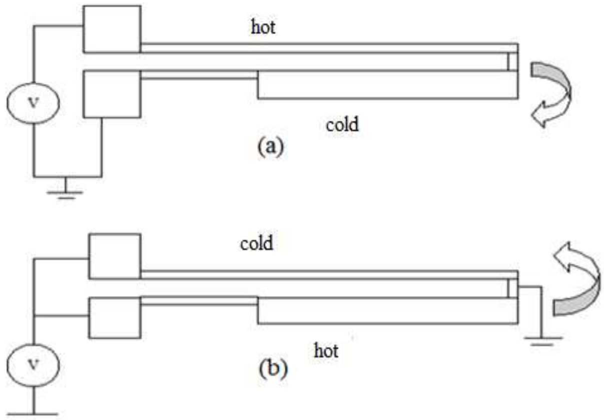

Figure 1: (a) Series Arrangement (b)Parallel Arrangement in Electrothermal Actuator

2. Design Concept

The total dimensions of the structure are within 705µm×235µm area, including contact pads. The two arms of the gripper are of different lengths but same cross-sectional area. The whole structure is made up of polysilicon as it is compatible with IC technology. The initial dimensions of the microgripper are as given in the table 1 and its design is shown in figure 2.

Table 1: Dimensions of the Microgripper

Parameter	Value
Length of the hot arm (L_h)	600µm
Length of the cold arm (L_c)	250µm
Flexure Length (L_f)	100µm
Width of the arms (W_h, W_c, W_f)	10µm
Gap between the arms (G_b)	10µm
Initial Opening (g)	15µm
Thickness	5µm

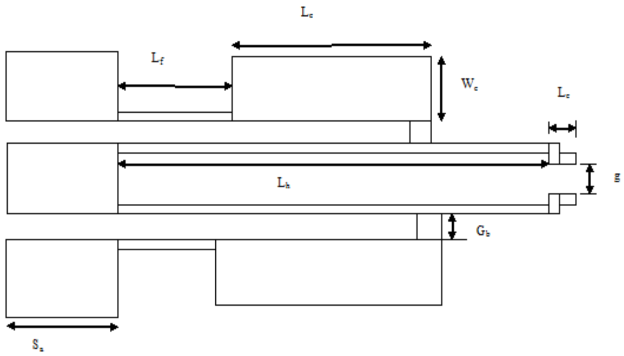

Figure 2: Design of Microgripper

3. FEM Simulation

The microgripper is designed and simulated in MEMS module of COMSOL Multiphysics 4.2a. According to the principle discussed in section I, the narrow arm gets more heated than the wider arm as shown in figure 3.

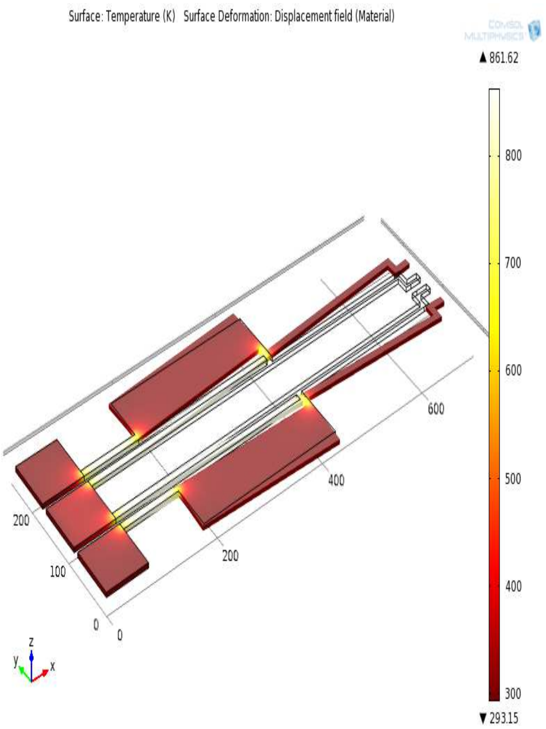

Figure 3: Temperature Profile

It is clearly shown in above figure that the gripping arms remain at room temperature which is one of the main advantage if this design. The maximum temperature lies in the middle of the hot arm i.e., 861K and displacement at the tip is 7.7µm at 3V as shown in figure 4.

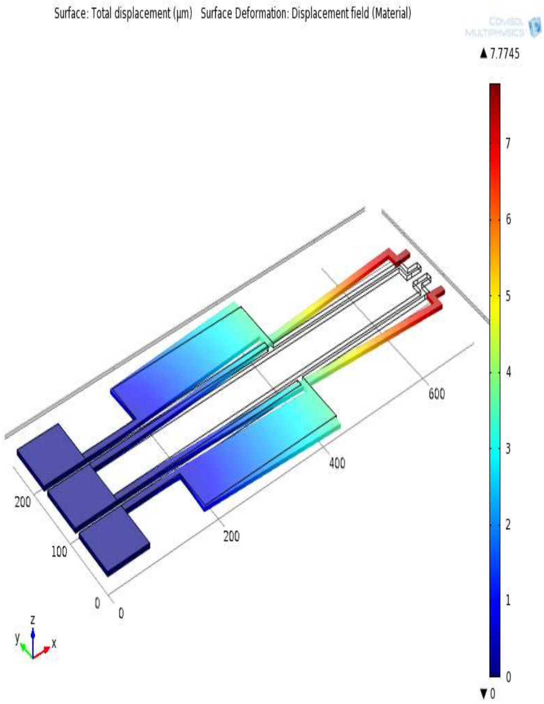

Figure 4: Displacement

4.Geometrical Optimization

The microgripper is geometrically optimized for improvement in its performance. The length of the hot arm is varied from 500µm to 700µm. With 700µm hot arm, displacement has increased to 11.08µm as shown in figure 5. Table 2 ang figure 6 clearly shows the variation of displacement withlength of the hot arm.

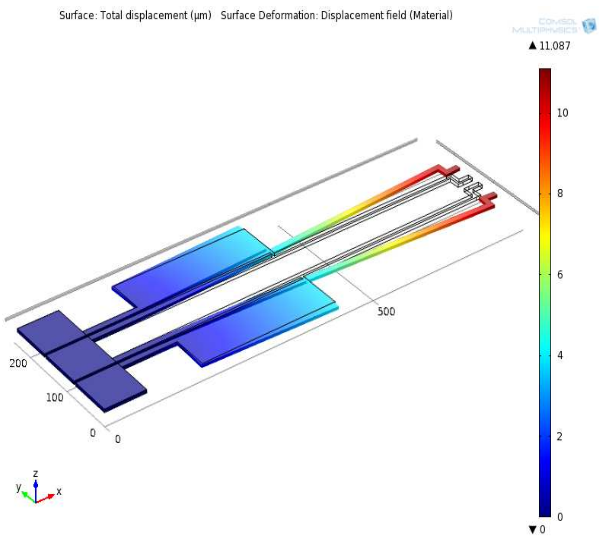

Figure 5: Displacement when L_h 700µm

Table 2: Variation of Displacement with L_h

Length of the hot arm (µm)	Displacement (µm)
500	7.36
600	7.7
700	11.08

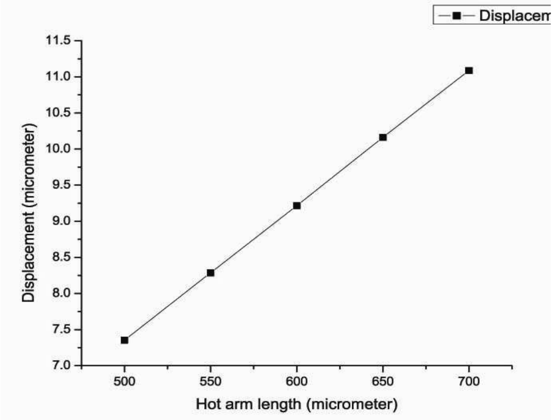

Figure 6: Displacement versus L_h

The gap between the arms (G_b) is also varied from 5µm to 15µm. On decreasing the gap, the displacement increases. Figure 7 shows the tip displacement with gap 5µm and figure 8 shows the variation of displacement with gap G_b

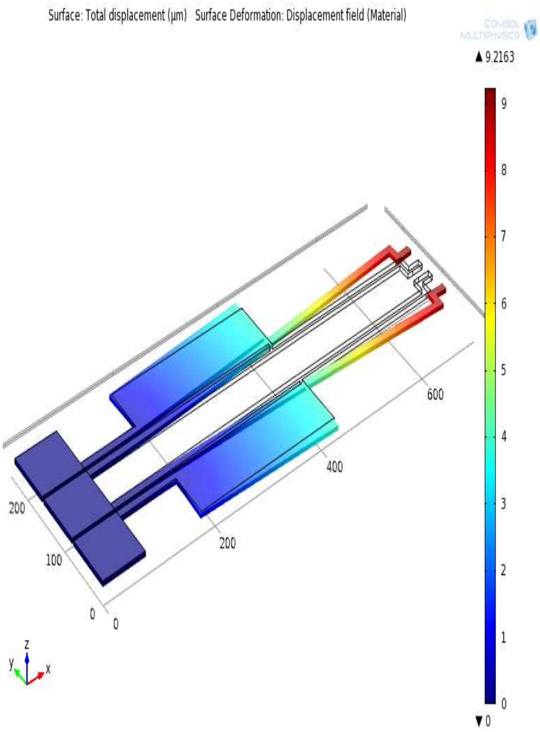

Figure 7: Displacement when gap 5µm

Table 3: Variation of Displacement with G_b

Gap between the arms (µm)	Displacement (µm)
15	6.71
10	7.7
5	9.22

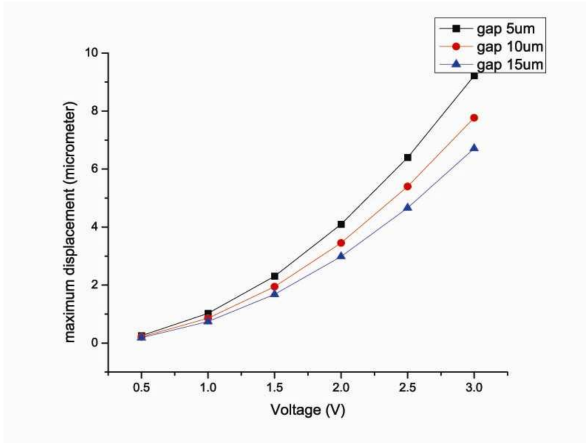

Figure 8: Displacement versus G_b

5. Conclusion and Future Scope

It has been found that the performance of electrothermal microgrippers is greatly affected by the dimensional variation. Longer hot arms and narrower gap between the hot and cold arm results in larger displacements. This design of microgripper can be used for manipulation purposes. In this work, only the effect of length of the hot arm and gap between the arms is realized. Further improvements can be realized by varying the other dimensions of the gripper like width of the cold arm, thickness. Also different materials can be used.

6. References

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7. Acknowledgement

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