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Design and Optimization of an Electro Thermally Actuated Micro Gripper

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ABSTRACT— A MEMS electro-thermal microgripper has been designed and discussed in this paper. The electro thermally actuated gripper consists of "hot-and-cold-arm" actuators. The micro-grippers are used to maneuver small delicate objects with nanometer scale precision and accuracy. Design parameters strongly influencing the performance of the gripper such as length of the hot arm, length and shape of the cold arm has been considered in order to optimize the performance. The gripper has a thickness of 25µm. Simulation of the device has been done using the COMSOL Multiphysics software.

KEYWORDS— MEMS, Electro thermal microgripper, Thermal Expansion.

I. INTRODUCTION

Micrograppers are microscopic tools which are designed specifically for handling objects in the range of micrometers to nanometers. They are ideal for variety of applications including sample handling, micro assembly, micro-factories, biological and biomedical research and parts handling in scanning electron microscopes. In micrograppers for providing the gripping force, actuating principle based on electrostatic forces is highly desirable. However they have small deflections and require large voltage to obtain large deflection. On the other hand actuation mechanism based on thermal expansion effect can provide a large force and displacement. The operating principle of thermally driven actuator is the expansion of

a microstructure with variable cross sections. Electro-thermal actuation is the preferred mechanism since it is able to produce large deflections at low activation voltages [1].

II. CONCEPT DESIGN

Micro grippers consist of a pair of tweezers to grab the objects and pair of actuators to provide the required force. The micro actuator consists of

1. hot arm (which is narrow)
2. cold arm (which is wide)
3. flexure

The resistance of the hot arm is higher than the cold arm since it is narrower. When voltage is applied to the anchors, current passes from one anchor to another through the hot and cold arms of the actuator. The hot arm gets more heated than the cold arm according to the relations:

$R = \rho L/A \quad \& \quad H = I^2R$ (1)

where ,
R – Resistance
L – Length
A – Area of the cross section of the arm
H – Joule heat produced in the arm
I – Current flowing through the arm

As a result of more heated hot arm, it deflects more than the cold arm. The arms are jointed at the free end which causes the tip of the actuator to move laterally towards the cold arm side [2,3]. Fig. 1 shows the schematic view of the electro thermal actuator.

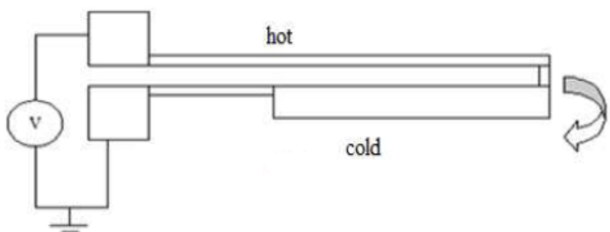

Fig. 1 Schematic view of electro thermal actuator

III. STRUCTURE AND DIMENSIONS

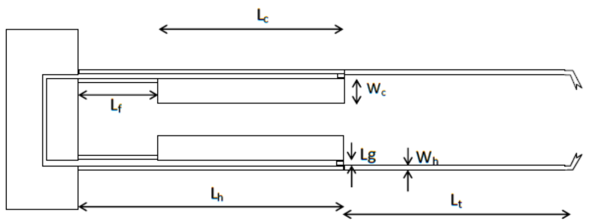

Fig. 2 Structure of the Micro gripper

The micro gripper consists of a pair of electro thermal actuators driving a pair of tweezers. The microgripper consists of major parts as hot arm, cold arm, anchors and tweezers. When the tips of the actuators move laterally because of the voltage applied, the tweezers attached to the actuators also move. This movement is used to grab the object. The entire structure is made up of silicon. The initial dimensions of the electro thermally actuated gripper are as given in the Table I.

TABLE I
DIMENSIONS

Geometric Dimensions	Values
Length of hot arm, L_h	200 µm
Length of cold arm, L_c	160 µm
Length of the flexure, L_f	40 µm
Length of the tweezers, L_t	200 µm
Gap, L_g	6 µm
Width of the hot arm, W_h	6 µm
Width of the cold arm, W_c	15 µm

IV. ANALYTICAL MODELING

The resistivity is a function of temperature and the formula is given by [4]

$$\rho(T) = \rho_0 [1 + \alpha_R (T - T_0)] \qquad (2)$$

where,
ρ_0 – Resistivity at a reference temperature
α_R – Temperature coefficient of resistivity
T_0 – Reference temperature

Thermal expansion of solids is modeled by [4]

$$\alpha_E = \Delta L / (L_0 . \Delta T) \qquad (3)$$

where,
α_E – Linear thermal expansion coefficient
ΔL – Change in length from L_0
ΔT – Change in temperature that causes the expansion

The lateral movement of the tip of the tweezers attached to the actuators can be estimated by [5]

$$\delta y = \frac{(a^4 - a^2 + 2a)Ar\alpha\Delta TL^2}{2*(5a^4I + a^4r^2A - 2a^3I + 5aI + r^2aA + I + a^5I - 2a^2I} \qquad (4)$$

where,
A – Cross-sectional area of the hot arm
I – Moment of inertia of the hot arm
L – Length of the actuator
a – Ratio of the length of the flexure to the length of the hot arm
α – Coefficient of thermal expansion
r – Gap between the hot arm and the flexure
ΔT – Net temperature difference.

Temperature distribution along the arm of the actuator is given by [6]

$$T(x) = \frac{V^2}{2L^2\rho K_p}(Lx - x^2) + T_0 \qquad (5)$$

where,
x – Position along the arm
V – Applied voltage
L – Length of the arm
ρ – Resistivity
k_p – Thermal conductivity of the material

V. FEM SIMULATION

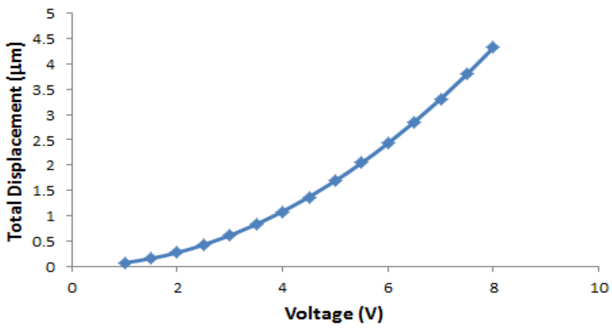

Fig. 3 Displacement Vs. Applied voltage

Simulation of the device has been done using the COMSOL Multiphysics tool. The joule heating and thermal expansion physics has been used to model the design. According to the principle described in the section II the hot arm gets more heated than the cold arm and moves laterally. Electric potential is applied to one of the anchors and the other is grounded. The total displacement increases with increase in the applied voltage and is shown in the Fig. 3. The displacement for the applied voltage of 8v is shown in the Fig. 4.

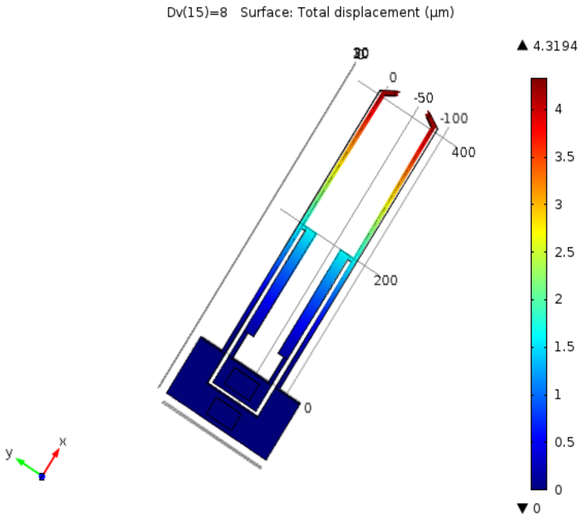

Fig. 4 Displacement

Von mises stress of the gripper is shown in Fig. 5. The maximum von mises stress of the structure is lesser than the maximum with stand-able stress i.e., yield strength of the material which is being used.

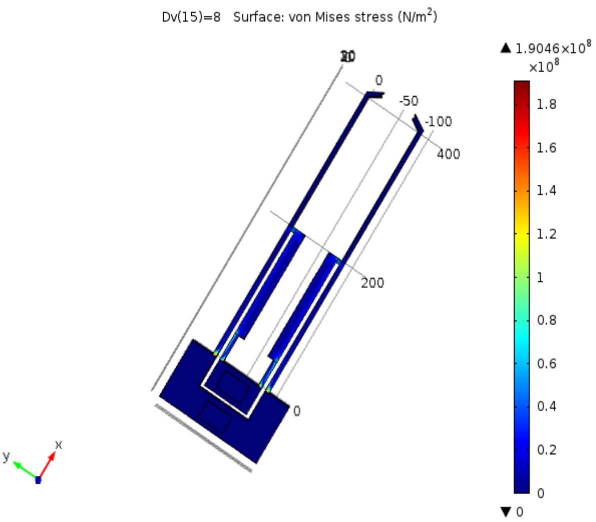

Fig. 5 Von Mises stress

VI. Optimization

The microgripper has been optimized for the improvement in its performance. The design parameters used to optimize the performance are the length of the hot arm and tweezers, shape of the cold arm and metal coating on cold arm.

A. Length of the hot arm and tweezers

The amount of deflection depends majorly on the geometry of the gripper [7]. Length of the hot arm is varied from 400µm to 500µm and the displacement has been observed. Table II Shows the variation of displacement with respect to the length of the hot arm and tweezers

TABLE II

Length Vs. Displacement

Length of hot arm	**Length of tweezers**	**Maximum Displacement**
200 µm	200 µm	4.3194 µm
225 µm	225 µm	5.0526 µm
250 µm	250 µm	5.8383 µm

B. Metal coating

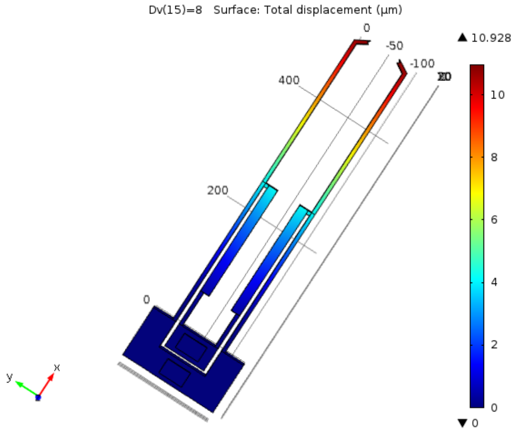

Fig. 6 Displacement when gold coated on cold beam

Displacement can be increased further by having a metal coating [8]. When gold is applied on the cold beam with the length of the hot beam and tweezers as 250 µm the displacement obtained is 10.928 µm as shown in Fig. 6.

C. Shape of cold beam

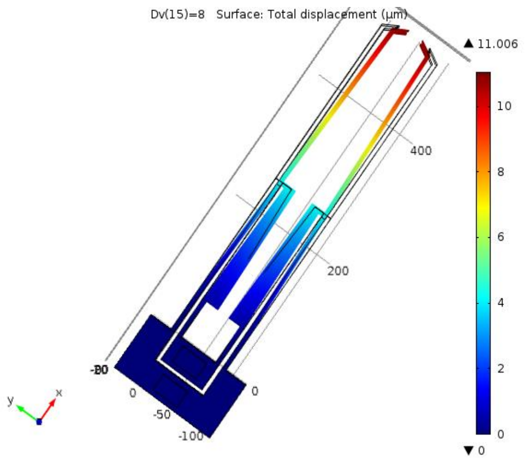

Fig. 7 Displacement when cold beam is of tapered shape

Another design parameter that affects the displacement is the shape of the cold beam. When cold beam has the tapered shape instead of the rectangular one, the displacement can be improved little further. With the tapered beam the displacement of 11.006 µm is being achieved. The displacement of the microgripper with tapered beam is shown in Fig. 7.

VII. Conclusion

Electro thermally actuated microgripper with actuators has been designed. The design has been optimized in order to increase the displacement. When the size of the arms and tweezers are increased the displacement increases. The shape of the cold arm also affects the displacement. The tapered beam results in larger displacement than the rectangular beam. Metals coating provides a considerable amount of increment in the displacement. Further improvements can be realized by varying other dimensions of the design and also different materials can be used.

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