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Abstract – Thermal micro actuators are widely used for large displacement, high accuracy and repeatability. The applications of these devices are in the fields of micro assembly, micro surgery and manipulation of micro particles. In this paper, the development of electro thermal micro actuator based on PMMA (Poly Meta Methyl Acrylate) is described. The paper presents the development of a new micro actuator for a microgripper which has a combination of asymmetric arm and bi-layer structure to completely eliminate the undesirable out of plane movement. Three models of electro thermally actuated polymeric micro actuators using low voltage of 0.1 V are designed and analyzed using COMSOL Multiphysics software. The results are discussed and compared to show the efficiency of the hybrid design. The hybrid design gives 2.5 µm of in plane gripping displacement and 0.02 µm out of plane displacement at 0.1 V.

Key words - *MEMS, micro actuator, microgripper, COMSOL elecrothermal actuator.*

I. INTRODUCTION

Micro actuator is one of the most important parts of microgripper. The microgripper is an important component of the system to hold, pick, manipulate and assemble mechanical micro components. For example, in the case of micro robot (size of few mm) where the components are in the order of micrometers which are produced using micro mechanical or micro electric mass fabrication process have to be assembled using microgripper. The general requirement of a microgripper is that it should be able to pick up and release a component at a specified position. The positional uncertainty during assembly should be well defined and components should not be damaged during assembly. Microgripper applications include assembly of micro components in manufacturing, electronics, information technology, optics, medicine and biology areas like diagnostics, drug delivery, biopsy tissue sampling, tissue engineering and minimally invasive surgery. Thermal micro actuators are widely used for large displacement, high accuracy and repeatability. The working principle electro thermal micro actuator is based on the Joule's Law and principles of thermal expansion. The Joule's Law states that a material crossed by an electric current will get some thermal energy. This results in collision of the flowing electrons and the atoms making the material. This collision between the electrons and atoms results in vibration which excites the surrounding atoms. The large amplitude of vibration results in increase of dimensions. This phenomenon is known as thermal expansion [1]. The materials with higher co-efficient of thermal expansion result in larger gripping displacement. Polymers have the highest co-efficient of thermal expansion than metals and semi-conductors [2-5]. Due to co-efficient of thermal expansion there is an increase in dimensions in all directions. So, it is necessary to direct and amplify the thermal expansion in dimensions to obtain an efficient thermal actuation suitable for application. The amplification can be done by using asymmetric thermal arm structure, bi-layer structure and bent-beam structure. Micro actuators are broadly classified into in plane and out of plane actuators. The in plane actuators move parallel to the substrate surface, whereas out of plane actuators travel perpendicular to it [6]. Many polymeric in plane and out of plane actuators have been demonstrated using asymmetric arm [7, 8], bi-layer [6, 9] and bent beam structures [10, 11]. However asymmetric arm structured micro actuator have undesired out of plane movement. The bi-layer structure of a microgripper gives diverging movement which is undesired. To overcome the above disadvantages, combination of asymmetric and bi-layer structure hybrid design can be used.

In this paper, three models of electro thermally actuated micro actuator for a microgripper is designed using PMMA substrate and gold electrodes. The design and analysis is done using COMSOL Multiphysics software. The first model is designed using asymmetric arm. The second model is design using bi-layer structure. The third model is designed using combination of asymmetric and bi-layer structure. The analysis results are discussed and compared to show the efficiency of the hybrid design.

II. DESIGN AND SIMULATION

A. Design of asymmetric arm structure (model 1)

The first model is designed using asymmetric thermal arm structure. The structure consists of some major parts such as fixed part or anchor, hot and cold under arm, flexure, and heaters. The design criterion for asymmetric arm structure is that the flexure should be as thin as possible. Because, when the flexure becomes this, more deflection of the thermal actuation tip can be generated by the different thermal expansion between hot and cold arm. Also in order to keep the actuator elastically deflecting, the flexure should be long enough. However, if the flexure is too long, the deflection of the thermal actuator tip will be reduced due to resistivity of additional material [14]. With the above design criteria, an asymmetric electro thermally actuated polymeric micro actuator is designed and analyzed.

The overall dimension is 80x10x100 µm. The dimensions of hot and cold arms are 10x10x100 µm and 2x10x150 µm respectively. The dimension of the flexure is 2x10x50 µm. The base anchor dimensions are 80x10x20 µm. Initial gap between the gripper arms is 20 µm. The gold electrode of 1 µm is sputtered on top of the base anchor for voltage supply as shown in figure 1. Due to this voltage supply, heat is generated. The material properties of PMMA and gold are listed in table 1.

Properties	Gold	PMMA
Co-efficient of thermal expansion	14.2x106 per K	70x10^{6} per K
Thermal conductivity	317 W/mK	0.19 W/mK
Heat capacity	129 J/Kg K	1420 J/Kg K
Density	19300 Kg/m3	1190 Kg/m3
Young's modulus	70x109 Pa	3x10^{9} Pa
Electrical conductivity	45.6x106 s/m	1x10-^{19} s/m
Poisson ratio	0.44	0.4
Relative permittivity	---	3

Table 1. Material properties of PMMA and gold.

B. Design of bi-layer structure micro actuator (model 2)

The second model is designed using bi-layer structure. This layer consists of two gripper arms of dimension 10x10x100 µm on a base anchor of 80x10x20 µm. The gold electrode is sputtered on the outer side of gripper arms in a pattern as shown in figure 2 to obtain bi-layer actuation.

C. Design of hybrid structure microactuator (model 3)

The third model is designed combining both asymmetric arm structure and bi-layer structure. The dimensions are the same as model 1. The gold electrode of 1 µm is sputtered on the outer side of gripper arms as shown in figure 3 to obtain the combination of asymmetric and bi-layer structure.

III. SIMULATION RESULTS

The above three models are analyzed using COMSOL Multphysics software for an applied voltage of 0.1 V. The first model gives a diverging displacement of almost equal in plane and out of plane displacement of 0.34 µm and 0.36 µm respectively. The converging displacement can be obtained by interchanging the thin and thick beam. However, the out of plane movement is undesired. The results are shown in figures 4 and 5. Figure 6 shows the gripping action and stress distribution.

The second model gives diverging displacement of in plane actuation of 0.8 µm. Converging movement can be obtained by sputtering the gold electrodes on the inner-side of the gripper arms. But the fabrication is very complicated in such a case. The results of model 2 is shown in figures 7and 8. Figure 9 shows the gripping action and stress distribution.

The third model gives a converging displacement of in plane displacement of 2. 5 µm and out of plane displacement of 0.02 µm. The maximum temperature obtained is 323 K. Here the out of plane displacement is almost completely eliminated. The results are shown in fig 10 and 11. Figure 12 shows the gripping action and stress distribution. Figure 13 shows the temperature displacement in the micro actuator.

Figures 14 and 15 shows the in plane and out of plane displacements of the three models respectively. It is observed that optimal design is the model 3 because, it has very good in plane displacement for very less voltage of 0.1 V, negligible out of plane displacement and very low working temperature of 323 K.

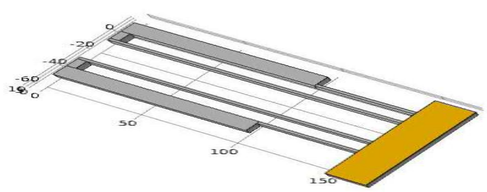

Fig.1 : Asymmetric arm structure micro actuator (model 1)

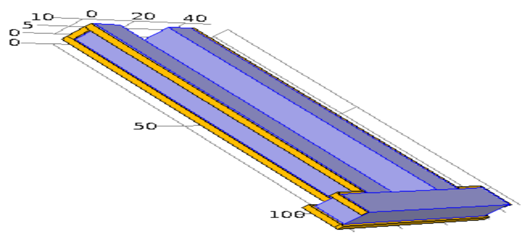

Fig. 2 : Bi-layer structure micro actuator (model 2).

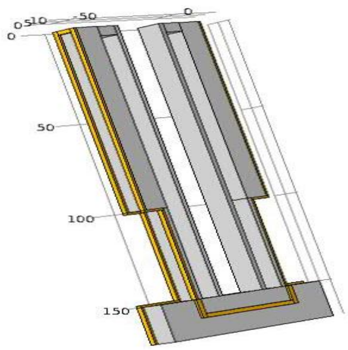

Fig. 3 : Hybrid structure micro actuator (model 3).

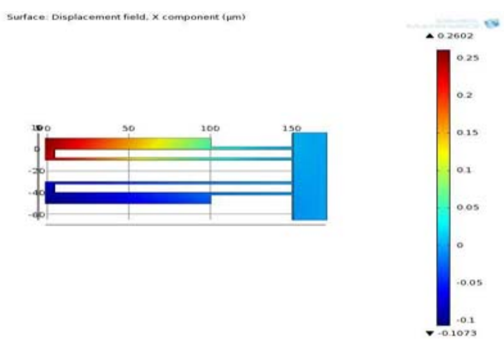

Fig. 4 : X axis displacement of model 1.

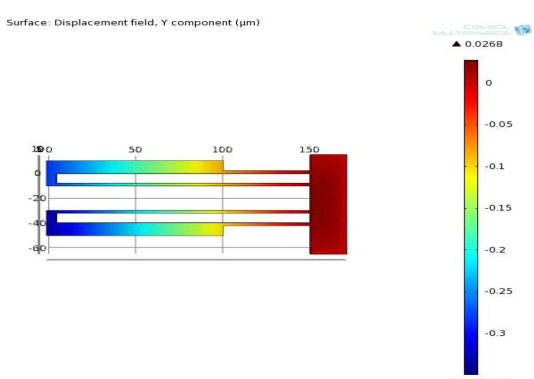

Fig. 5 : Y axis displacement of model 1.

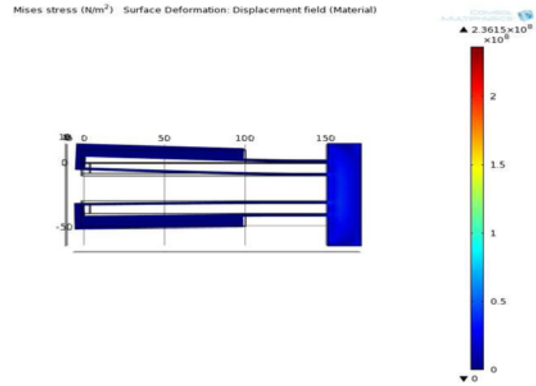

Fig. 6 : Stress distribution of model 1 at 0.1 V

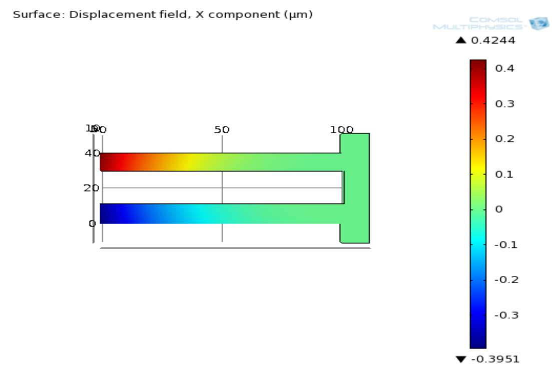

Fig. 7 : X axis displacement of model 2

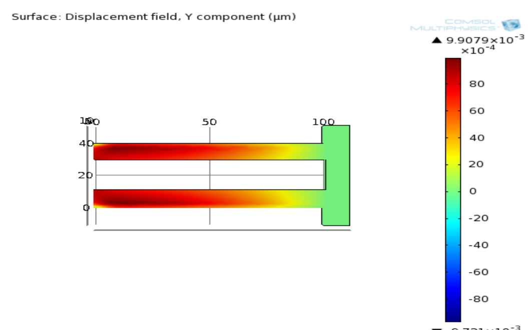

Fig. 8 : Y axis displacement of model 2

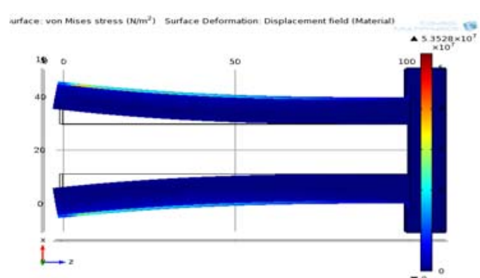

Fig. 9 : Stress distribution of model 2 at 0.1 V.

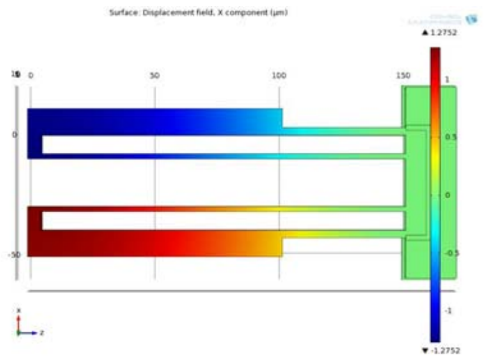

Fig. 10 : X axis displacement of model 3.

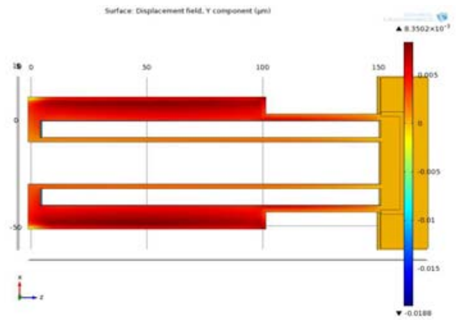

Fig. 11 : Y axis displacement of model 3.

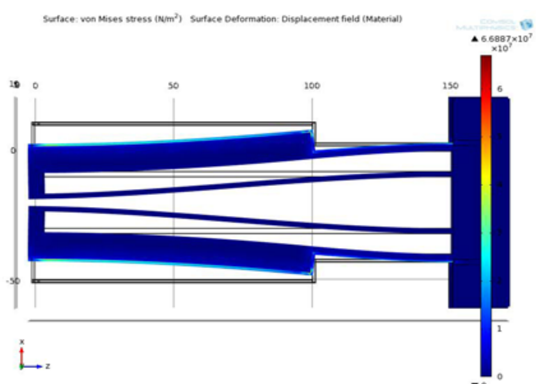

Fig. 12 : Stress distribution of model 3 at 0.1 V.

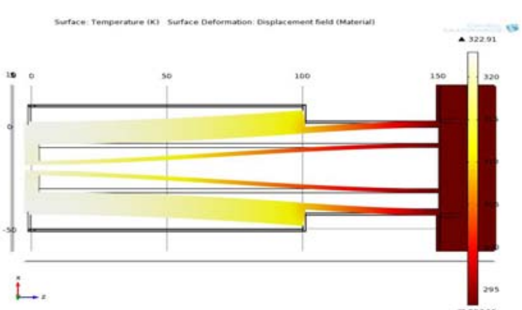

Fig 13 : Temperature distribution of model 3 at 0.1 V

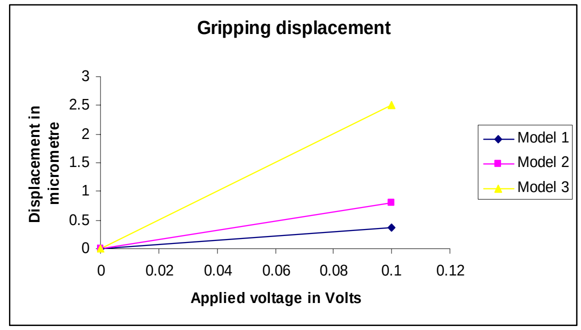

Fig. 14 : Gripping displacement of actuators arms.

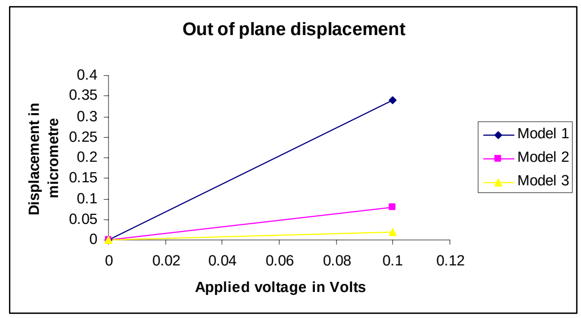

Fig. 15 : Out of plane displacement

IV. CONCLUSION

Micro actuator is an important part of microgripper. The electro thermally actuated micro actuators are designed using asymmetric arm and bi-layer structure. These structures have disadvantages such as divergent displacement and more out of plane movement. These disadvantages can be overcome by using a hybrid design structure using a combination of asymmetric arm and bi-layer structure. Three models of electro thermally actuated polymeric micro actuators have been designed using COMSOL Multphysics software based on PMMA. The results obtained are discussed and compared. The hybrid design is found to be the optimal model which gives very good displacement of 2.5 µm at 0.1V applied voltage and minimize the out of plane movement to a large extent. Thus, this micro actuator can be used in microgripper for better accuracy and gripping of micro particles.

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