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Design and Finite Element Analysis of Electrothermal Compliant Microactuators

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Abstract: Electrothermal actuators are capable of providing larger displacements compared to electrostatic actuators. Thermal actuators are of two types. Bimorph thermal actuator and single material Electro Thermal Compliant (ETC) actuator. Bimorph actuators are composite structure made of two or more layers of different materials. In this work ETC device has been studied for different geometry. For this purpose, four designs for ETC actuators with the same material properties and same dimensions are studied: one with rectangular beam without gold layer, the second one is rectangular beam with gold layer, the third one tapered beam design 1 with gold layer and the fourth one is tapered beam design 2 with gold layer. These modifications are adopted to improve the actuator displacement. The gold layer deposition increases the displacement and also the direction of deformation towards hot beam. A maximum deflection of 38 µm is obtained with tapered beam design 2.

Keywords: Electro thermal actuator, Gold layer, Design, Improved Displacement

1.Introduction

Micro Electro Mechanical Systems (MEMS) have been widely used in many areas such as electronics, biotechnology, and measurement. MEMS generally consist of microactuators and microsensors. The microactuator is the core part that provides motion. As compared with other types of microactuators, the electro-thermal microactuator has the advantages of robust structure, large output force and easy operation. Electrothermal microactuator is generally composed of two cantilever beams (arms) joined at the free end. This device generates deflection through asymmetric heating of the hot and cold arms with different cross-section or different length. The cold arm and hot arm are usually made of same material. Electrical current was passed through the actuator from one anchor to another and the higher current density in the narrow beam makes it to heat and expand thus producing an in-plane actuation towards cold beam side. When current pass through the microactuator, the higher resistance in the longer or thinner hot arm causes it to heat and expand more than the shorter or thicker cold arm. Therefore, this differential expansion forces the tip of device to move, thus generating tip deflection. Guckel et al [1] produced 'U' shaped actuator and analyzed the arcing motion at the tip of the actuator. In their research, the actuator composed of two in-plane cantilever beams with the free ends connected to each other. One beam had a narrower cross-section and the other wider cross-section. The actuator was anchored at the fixed ends. Electrical current was passed through the actuator from one anchor to another and the higher current density in the narrow beam makes it to heat and expand thus producing an in-plane actuation towards cold beam side. Comtois et al [2] developed micro polysilicon thermal actuator. The relationship between input power and output force was analyzed. Comtois et al [3] proposed a design that has several actuators in array to get larger output force. Reid et al [4] designed micro thermal actuators which will suitable to various microdevices such as micromirrors, micromotors. Huang et al [5] analyzed the effect of beam length and gap width on the displacement of the actuators. Chen et al [6] has designed a new model with an additional metal layer (gold) has been added on top of the wider beam layer to decrease the resistance, and to generate a bigger tip deflection. S.M.Karbasi et al [7] did a comparative study between different designs of electro thermal microactuators with emphasis on optimal design and performance key factors. They also developed an analytical and Finite Element Method (FEM) models and the models are validated with experimental results in literature. D. Yan et al [8] designed and tested a new electro thermal microactuator with bidirectional vertical motion. They modified the existing 'U' shape structure's in plane actuation to create a vertical motion. Chi – Ching-lo et al [9] presented a dynamic model for analyzing the static and dynamic performance of electro thermal microactuator. In their model, they adopted a lumped model approach that decomposes the electro-thermal-mechanical system into a series of electrical resistors, heat resistors, heat capacitors and a mechanical frame. N. Chronis et al [10] developed a SU-8 based electrothermally actuated polymer gripper consist of two hot and two cold arm actuators. And they used SU-8 due to the high thermal expansion coefficient of SU-8 compared to silicon and metals allow the higher displacement with low voltages. A. Alwan et al developed an integrated electro thermal and electro static actuators and produced hybrid actuation schemes and which provides low power consumption and high output force. A. Geisberger et al [12] presented a range of issues on modeling electro thermal microactuators including the physics of temperature dependent material properties and finite element modeling techniques. In this work ETC device has been studied for different geometry. The layout of ETC actuator is shown in Figure 1. This device consists of two beams with variable cross sections connected at free end. For this purpose, four designs for ETC actuators with the same material properties and same dimensions are studied: one with rectangular beam without gold layer, the second one is rectangular beam with gold layer, the third one tapered beam design 1 with gold layer and the fourth one is tapered beam design 2 with gold layer. These modifications are adopted to improve the actuator displacement.

Figure 1. Electrothermal compliant actuator

2. Use of Comsol multiphysics

The designs are simulated in COMSOL 4.2 version. The actuator operation involves three coupled physics namely electric current conduction, heat conduction and stresses due to thermal expansion. Material properties are given in table 1.

Table 1: Material properties used for simulation

Sl.no	Material	Properties
1.	Polysilicon	Young's modulus :169 [GPa]
		Poisson's ratio : 0.3
		Coefficient of Thermal expansion :2.568e-6 [1/K]
		Electrical Conductivity :0.25e5 [S/m]
2.	Gold	Young's modulus : 80 [GPa]
		Poisson's ratio : 0.3
		Coefficient of Thermal expansion : 14.2e-6 [1/K]
		Electrical Conductivity : 45.6e6 [S/m]
3.	Aluminum	Young's modulus :70GPa
		Poisson's ratio : 0.3
		Coefficient of Thermal expansion : 23.1e-6 [1/K]
		Electrical Conductivity : 35.5e6 [S/m]

The finite element model of the actuator using COMSOL software is shown in figure 2

Figure 2. COMSOL model of ETC device with gold layer

The actuator is electrothermally actuated. Temperature gradient develops as electrical current passes through the suspended beams with electrical resistance. The concept of energy conservation principle [13] is applied. The steady-state energy equation with a resistive heating source can be presented as

$$\Delta\left(k\Delta T\right)+\frac{\underline{E}^{2}}{\rho_{c}}=0 \qquad (1)$$

where K, $\underline{E}$, ρ_c and ΔT and are thermal conductivity coefficient, electric field, electric resistivity and temperature difference respectively.

2.1. Thermal expansion

Electrical current passes through the actuator from anchor to anchor, and the higher current density in the hot beam causes the actuator to heat

and expand more than in the cold beam, thus produced lateral arcing motion toward the cold beam side. For one-dimensional structural element, the axial deflection,
ΔL, due to thermal expansion can be obtained by

$$\Delta L = \alpha L \Delta T \tag{2}$$

where α is the coefficient of thermal expansion of material, L is the original length of the element and ΔT is the temperature difference. The boundary conditions which is used for finite element simulation are
1. Bottom surfaces of the anchors are fixed in all degrees.
2. A DC voltage of 10 volts is applied at the bonding pads.
3. Temperature of 300K is applied as the ambient temperature.

The layout of the ETC actuator which is used in simulation is shown in figure 3. The dimensions are given in table 2.

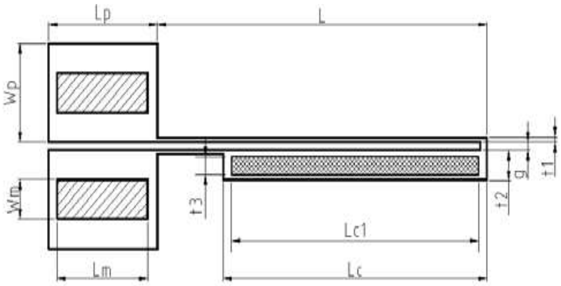

Figure 3. Geometric dimensions electro thermal actuator.

Table 2: Dimensions of Electro thermal actuator

Symbol	Description	Dimension (µm)
L	Total beam length; length of an element	200
L_c	Length of cold beam	160
g	Gap between cold and hot beam	2
t_1	Hot beam width	2
t_2	Cold beam width	15
L_p	Length of pads	66
L_m	Length of anchors	56
W_p	Width of pads	50
W_m	Width of anchors	20
L_{c1}	Length of gold layer	150
t_3	Width of gold layer	9

3. Results and Discussions

The actuator without an additional gold layer is analyzed first. Its geometric dimensions are listed in table 2 and the associated material properties in table 1. Figure 4 and figure 5 shows total displacement and current density respectively. The tip deflection of the actuator shows an increasing relationship with the voltage. The deflection of about 9 µm is obtained with this design.

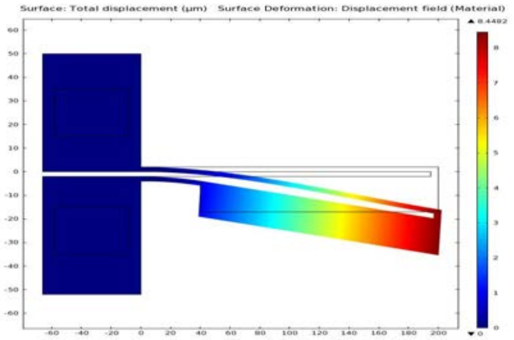

Figure 4. Displacement of Rectangular beam without gold layer.

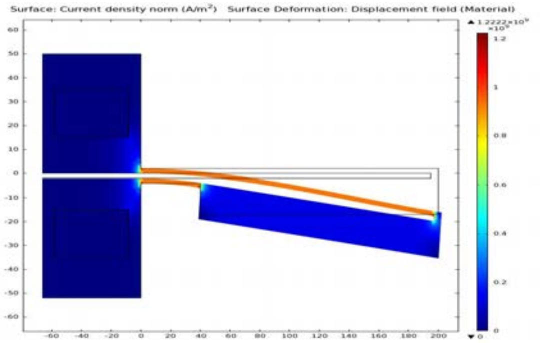

Figure 5. Current density of Rectangular beam without gold layer.

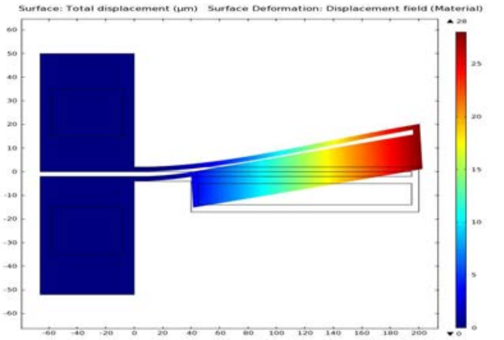

Figure 6. Displacement of Rectangular beam with gold layer.

The addition of gold layer deposition to the cold beam reduces the resistance of the cold beam and hence reduces the temperature of the cold beam and increases the tip deflection to 28 μm as in figure 5.

To improve the displacement further, two more designs are also developed as tapered design 1 and tapered design 2. The deflection plots of the designs are shown in figure 7 and figure 8 respectively. The displacement is further increased due to the asymmetry of the cold and hot beam structure. The displacement of about 34 μm is obtained in design 1 and the displacement of about 38 μm is obtained from design 2.

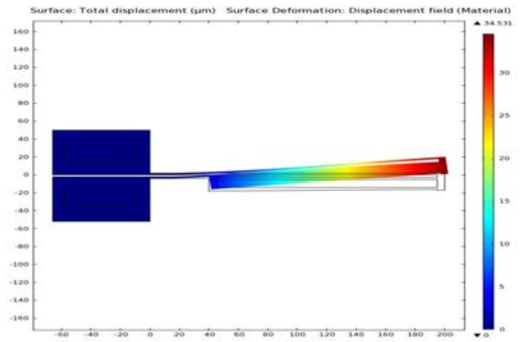

Figure 7. Displacement of tapered design 1 with gold layer.

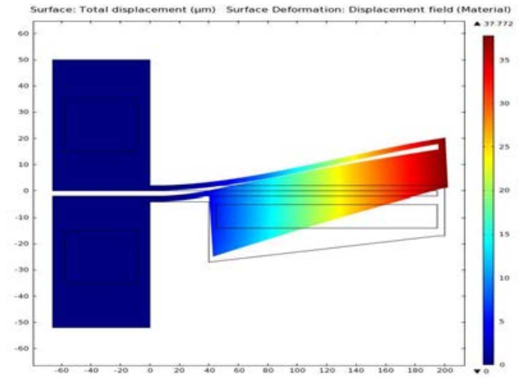

Figure 8. Displacement of tapered design 2 with gold layer.

4. Conclusions

A two dimensional finite element model of an electro thermal actuator was developed. The gold layer deposition increases the displacement and also the direction of deformation towards hot beam. Two more design as tapered beam design 1 and tapered beam design 2 is also developed. A maximum deflection of about 38 μm is obtained with tapered design 2.

5. References

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