Modelling & Simulation of Novel Three Arm MEMS Actuators & Its Application

Jagadeesh Pandiyan¹, M. Umapathy², S. Balachandar³, M. Arumugam⁴, S. Ramasamy⁵, Nilesh C. Gajjar⁶

¹Larsen & Toubro Limited, e-Engineering Solutions, NH-8, Chhani, Vadodara-391740, Gujarat, India. Email: jagadeeshpandiyan@yahoo.co.in

²Department of Instrumentation & Control Engineering, National Institute of Technology, Tiruchirappalli-620015, Tamilnadu, India. Email: umapathy@nitt.edu

³Department of Electronics & Communication Engg, Arunai Engineering College, Tiruvannamalai-606603, Tamilnadu, India. Email: balachandar_ss@yahoo.co.in

⁴Director R&D, Arunai Engineering College, Tiruvannamalai-606603, Tamilnadu, India. Email: arumugamaec@yahoo.com

⁵Department of Electrical & Electronics Engineering, N P A Centenary Polytechnic, Kotagiri-643217, Tamilnadu, India. Email: rams_npacpt@yahoo.co.in

⁶Department of Mechanical Engineering, Institute of Technology, Nirma University, Ahmedabad -382481, Gujarat, India. Email: nileshcgajjar@yahoo.co.in

Abstract. This paper presents the design and Finite Element Model (FEM) simulation of a novel electrothermal microactuators and arrays. It is a single material microactuator which deflects at its tips by differential thermal expansion of its constituent parts. The electrothermal actuator consists of three thin arms, three thin blades and two electrical connection pads. The goal of this coupled electrothermal actuator design was to multiply the force by adding the individual contributions of all the three actuators. The difference in magnitude of blade deflections depends on the geometrical characteristics of the actuators. The thermal deformation and thermal stability are easily controllable. The simulation employing ANSYS/Multiphysics software results include force, deflection, thermal stress, ideal electrothermal actuator and array geometries. The main advantage of this electrothermal actuator is large deflection of blades with very low actuation voltage in comparison with electrostatic actuators. A typical application in a micromirror is shown to illustrate the utility of these actuators and arrays.

Keywords. Finite Element Model, microactuator, electrothermal actuator, micromirror, heatuators.
1. Introduction
In recent years, microactuators are a hot topic in current research, and a variety of microactuators has already been established opening the door to a wide field of applications. Microactuators converts energy into appropriate action capable of producing micron-scale motion for positioning individual elements in microelectromechanical systems (MEMS) [1]. The various modes of actuation are electrostatic, magnetostatic, piezoelectric, hydraulic and thermal [2]. Among these various methods of microactuation techniques, the thermal expansion actuations have the characteristics of large deflections, large forces, and low driving voltage. Here, new shape of actuator structure is proposed to obtain different magnitudes of deflection from the individual components and to achieve linear motion with larger deflection.

2. Electrothermal Actuators
It is a U-shaped microactuator as shown in Fig.1 converts electrical to mechanical energy through ohmic (Joule) heating and the thermal expansion of polysilicon. The conventional electrothermal microactuators consist of a hot arm (or thin arm), a cold arm (or blade), flexure element, anchor and contact pads as shown in Fig.1. When a voltage difference is applied across the contact pads, current flows through the thin arm and blade causes more resistive heating in the hot arm than in the cold arm due to larger current density in the narrower hot arm. The hot arm is heated to a higher temperature than the cold arm. When the power is removed, the microactuator returns to its equilibrium state. This magnitude of the lateral displacement of actuator tip mainly depends on the geometrical characteristics of the actuators individual components and also actuation voltage. This temperature differential causes the hot arm to expand along its length, thus forcing the actuator tip to move laterally in an arc-like pattern towards the cold arm side.

3. Novel Electrothermal Actuators
The novel electrothermal microactuator design [3] is shown in Fig 3. It consists of three pairs of thin arms and blades, flexure elements, anchor and contact pads. The ‘hot’ and ‘cold’ arms pairs are
connected serially, i.e. each pair of hot arm end is joined with the flexure element of the adjacent pair through a small turn. The potential difference is applied across the contact pads. The arm A, B and C indicates the upper, middle, and lower ‘hot’ & ‘cold’ arm respectively.

![Figure 3. Schematic view of basic novel electrothermal actuator](image)

The non-uniform heating is likely to give more deformation at the desired points than uniform heating of the whole structure and it can be achieved through internal Joule heating. By using this new shape of actuator, linear motion and variable deflection level at the desired points can be easily achieved. In this novel configuration the direction of movement of the blade and magnitude of each pair are easily controllable for different geometry and actuation voltage. The dimensions of the above model are listed in Table.1.

Another configuration is shown in Fig.4. basically it has the same structure as that of model of Fig.3. In order to get more displacement at the desired points (marked as B), the width of the cold arm is to be reduced to twice its hot arm. According to the required displacement level, the dimensions of the turns and middle arm are allowed to vary. And the position of the contact pads has been changed from previous model that prevents the touching of movable turns with the pads when applying higher voltage across the pads.

![Figure 4. Schematic view of modified electrothermal actuator](image)

4. Simulation Results
The modeling and simulation were done using ANSYS software. In the new linear electrothermal actuators, the maximum displacement takes place at the joining end of middle thin arm and blade, which give a translational motion. The temperature at the middle configuration i.e. second thin arm and blade is higher than the other, so that it expands more than the other pairs of the device. Three different magnitude level of movement takes place at the three different ends as shown in Fig.5, which are useful for positioning other elements independently. The non-uniform heating of the structure, causes the point B to deflect more than the other ends A and C. By changing the structure of the geometry of the existing arrays, the displacement level can be increased. These actuators were designed with various dimensions and simulated for different required displacement and forces. There
is a translational motion in the turns with the same magnitude level of end B, but in opposite direction as shown in Fig.6.

![Figure 5. Deformed shape of the basic novel electrothermal actuator](image)

**Figure 5.** Deformed shape of the basic novel electrothermal actuator

![Figure 6. Deflected configuration of modified novel electrothermal actuator](image)

**Figure 6.** Deflected configuration of modified novel electrothermal actuator.

The simulation result is shown in Fig.7. indicate the deformation shape of the modified electrothermal actuators and larger tip movement in the middle arm when compared to basic model. In the new linear electrothermal actuators, the maximum displacement takes place at the joining end of middle thin arm and blade.

The temperature distribution of the model is shown in Fig.7. The temperature is gradually increasing from the upper contact pad to the lower contact pad and both contact pads are maintained at the same temperature. It clearly shows that the temperature in the middle hot and cold arm is higher, when compared to the other upper and lower hot & cold arm. The temperature at the turns that connects the hot arm to the flexure element is slightly lower than tip temperature. The length of the three hot and cold arms can be adjusted for different temperature profile and deflection in the tip of middle hot and cold arm also reflects changes.

![Figure 7. Temperature distribution](image)

**Figure 7.** Temperature distribution.

The arrays of electrothermal actuators are called heatuators which are connected together at their blade tips to multiply the force generated by the individual actuators that can be effectively used to operate other micro devices & systems like micromirror, microengine, micromotors etc., The heatuator assembly is shown in Fig.8. which consist of two electrothermal actuators joined at the tip of the
middle arm. According to the simulation, reducing the width of cold arm enhances the movement in heatuators.

![Figure 8. Heatuator.](image)

The dimensions of the novel & modified electrothermal actuators are given in Table.1. and thermo-physical properties are given in Table.2.

| Table 1. Dimensions of electrothermal actuator (All dimensions in μm) |
|---------------------------------------------------------------|
| Component | Notation | Value 1 | Value 2 |
| Cold arm length | d1 | 120 | 160 |
| Cold arm width (basic) | d2 + d6 | 17 | 14 |
| Cold arm width (modified) | d2 + d6 | 4 | 4 |
| Hot arm length | d3 | 150 | 200 |
| Hot arm width | d4 | 2 | 2 |
| Flexure length | d5 | 30 | 40 |
| Flexure width | d6 | 2 | 2 |
| Hot and cold arm separation gap | d7 | 2 | 2 |

| Table 2. Thermo-physical properties value |
|-------------------------------------------|
| Description | Value | Units |
| Young’s modulus, E | 169.0 | G Pa |
| Poisson ratio, ν | 0.22 | |
| Coefficient of linear thermal expansion, α | 2.9 | μm m⁻¹K⁻¹ |
| Thermal conductivity, k | 2.9 | W m⁻¹K⁻¹ |
| Electrical resistivity, 1/κ | 2.3 x 10⁻⁵ | Ω m |

The above values for dimensions and thermo physical properties are employed for the modeling and simulation. The model was simulated with different dimension to maximize the tip displacement and temperature profile was studied.

5. Application

The optical scanner is one of the optical components, which has wide application in optical industry such as bar code scanning, display projection system, etc. The optical scanner consists of hinged micromirror plates connected to electrothermal actuator arrays or heatuators. The micromirrors are electro mechanical devices that reflect and/or modulate light. The mirror is a moveable plate so that
light reflected in a micromirror can be directed to different areas by changing the tilt angle of the micromirror.

The micro-optical scanner is shown in Fig.9, using the novel electrothermal actuator arrays. The actuation forces of the two actuators are coupled to increase the force in order to actuate the micromirror. The middle arm of these two actuators are coupled and connected to lower portion of the micromirror assembly with proper key lock arrangement. Two microhinges are provided at the base plate of the micromirror assembly.

**Figure 9.** Micromirror Assembly.

6. Conclusion
The paper describes the design, modeling and simulation of novel electrothermal actuators. These actuators are capable of producing high forces and translational deflections by proper coupling of the middle arm of each actuator. The actuators produce linear displacement at the end of the middle arm tip, so they are easily connected together to achieve the desired actuating force. Also typical applications are discussed.

7. References
[1] J.H. Comtois, M.A. Michalicek, & C.C. Barron, “Characterization of electrothermal actuators in a four-level, planarized surface-micromachined polycrystalline process”, Proc. IEEE International Conference On Solid-State Sensors and Actuators, Chicago, IL, pp. 769-772, Jun 1997.
[2] T. Moulton & G.K. Anathasuesh, “Micromechanical devices with embedded electro-thermal-compliant actuation”, Proc. ASME Winter Annual Meeting volume MEMS-1, pp. 553-560, 1999.
[3] A. P. Jagadeesh, “A Novel MEMS Electrothermal Actuators and Arrays”, Proc. INAE Conference on Nanotechnology (ICON - 2003), Chandigarh, India, pp. 621-629, Dec 2003.