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Electro Thermal Analysis of a MEMS Micro Actuator by Finite Element Method

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Abstract— Microelectrothermal actuator is a component of MEMS devices which is based on the principle of thermal expansion of the arm of the device due to temperature difference and generated current for an input voltage. The microactuator produces deflection due to the asymmetric thermal expansion of the two arms. Upon application of a potential difference, the thin arm expands more than the wide arm, leading to motion of the actuator tip towards the wide arm. The present work addresses simulation of thermal gradients and thermal fluxes generated in a MEMS actuator due the current and heat produced. Finite Element Method(FEM), a numerical Technique has been used for this purpose. Finite Element Analysis has been carried for the electro thermal analysis of the actuator using a commercial software ANSYS with coupled filed method. The results are established for the heat and current produced due to a change in the potential difference of the actuator pads by comparing with theoretical results and validated.

1.0 Introduction:

Micro-electro-mechanical systems (i.e., MEMS) are integrated systems of microelectronics (IC), microactuator and, in most cases, microsensors [1]. MEMS technology offers unique advantages including miniaturization, mass fabrication and monolithic integration with microelectronics, and makes it possible to fabricated small devices and systems with high functionality, precision and performance. More important, MEMS technology can enable new circuit components and new functions [2] and [3].

According to the differences in drive principles,they can be divided into electrostatic., piezoelectric.,electromagnetic. and electrothermal[4].• Among these types of actuator, the electrothermal actuator has the advantages of a large driving force and large driving displacement under a low driving voltage. It does not depend on the distance change of the electrode [5, 6].

Electrothermal actuation is widely adopted in MEMS devices among other methods of actuation (e.g. electro thermal, piezoelectric, etc.) [7]. Also, to achieve higher amplitude of actuation, it is necessary to increase the applied voltage [8]. One of the problems associated with increasing the applied voltage is the joule heating effect [9]. An increase in the temperature of electro statically actuated MEMS device can greatly affect the performance of the device. This heating side effect will result in different problems such as, generating thermal stresses [10], straining the microstructure, and even changing the mechanical properties of the vibrating structure material which result in changing the expected resonance frequency of the device [11]. The multi physics simulation of thermal MEMS actuators is often obtained from Finite Element Modeling (FEM) or Finite Element Approximation (FEA). Lerch *et al.* have studied the temperature distribution and deflection of a microstructure using a Finite Element (FE) analysis [12]. Lin and Chiao have used FE simulation to study the E-T response of a line-shape microstructure [13]. Mankame introduced a comprehensive thermal model for the FE simulation of E-T compliant structure [14].

2.0 FINITE ELEMENT MODELING AND ANALYSIS

The geometric design parameters of the actuator are shown in Figure-2.1. All the parameters represented are in microns.

The wide arm of the modeled parameter is on the top side instead as shown in Figure. The dimensional values of the actuator are shown in Table-2.1.

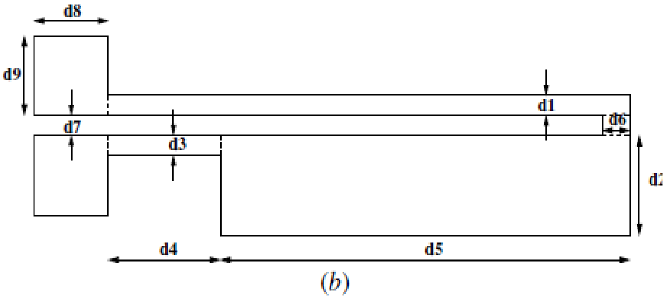

Figure 2.1: Geometric design parameters of the thermal microactuator

Notation	Width of thin arm	Width of wide arm	Thickness of flexure	Width of flexure	Length of wide arm
Item	d_1	d_2	d_3	d_4	d_5
Dimension value (μm)	40	255	40	330	1900
Item	d_6	d_7	d_8	d_9	d_{11a}
Dimension value (μm)	90	75	352	352	20

Table-2.1.: The dimensional values of the actuator

The 3-dimensional element SOLID227 with thermal conduction capability has been used for discretization. The element has eight nodes with a single degree of freedom, temperature, at each node. The element is applicable to a 3-D, steady-state or transient thermal analysis. The element also can compensate for mass transport heat flow from a constant velocity field. The element simulates the coupled thermal-electric-structural response. A mesh size of 0.1 has been used for discretization. The meshing is refined at the places where there is a change in cross section.

The element has ten nodes with up to five degrees of freedom per node. Structural capabilities include elasticity, plasticity, hyperelasticity, viscoelasticity, viscoplasticity, creep, large strain, large deflection, stress stiffening effects, and prestress effects. The mesh of the model in X-direction for 2D view is shown in Figure-2.2.

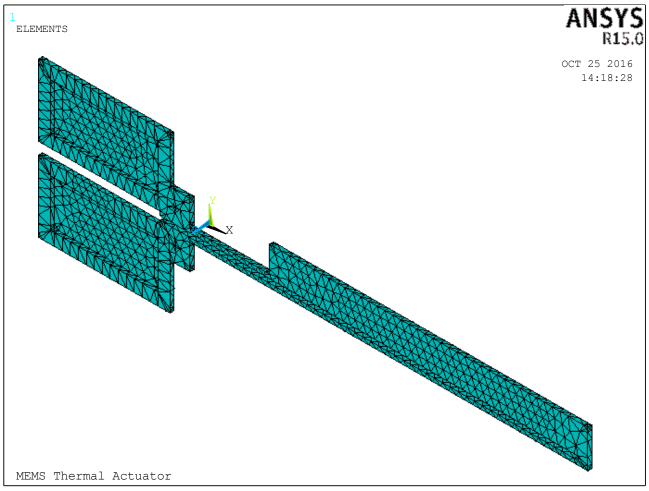

Figure-2.2: Mesh of the actuator in 2D –X direction

To define material properties for this analysis, it must be converted the given units for Young's modulus, resistivity, and thermal conductivity to μMKSV units. The units have been converted to μMKSV. The bottom surfaces of the anchors are fixed in all degrees of freedom to simulate the practical bonding situation . Electrical power with different voltage is applied at the bonding pads so that current passes through the actuator from anchor to anchor.

Temperature gradient develops due to thermal conduction and thermal convection occurs on the boundary surfaces where 25◦ C is assumed as the ambient temperature. It is assumed that the polysilicon is homogeneous, linear and isotropic with a Young’s modulus *E*=170 GPa. Residual stresses and warping resulting from fabrication process are ignored. The coefficient of heat conduction is 0.034 W mm^{-1} ◦ C^{-1} and the coefficient of natural convection is 50 μW mm^{-2} ◦ C^{-1}.

3.0 RESULTS AND DISCUSSION

The variation of heat flux generated with increase in voltage at constant temperature (40°C) is shown in Figure-3.1. From the figure, it is understood that the heat flux generated in Y-direction, i.e., along the width of the actuator is more than the other direction (Thickness & Length). The maximum value of heat flux generated is 1.2×10^9 J/mm^2).

The distribution of the thermal flux within he actuator is shown in Figure-3.2. The minimum and maximum values of Thermal flux -.213E^{+10} and .174E^{+10} J/mm^2 at the actuator displacement of 3.06665µm.

The variation of thermal gradients with increasing voltage in X,Y and Z directions is shown in Figure-3.3. It is seen that the thermal gradient variation is uniform in X and Z directions and is different and maximum in Y-direction. Similarly, the thermal gradients at 5V and 40°C are shown in Figure-3.4.The minimum and maximum values of Thermal gradients at 5V are -11.613 and 14.2039 at the actuator displacement of 3.06665µm.

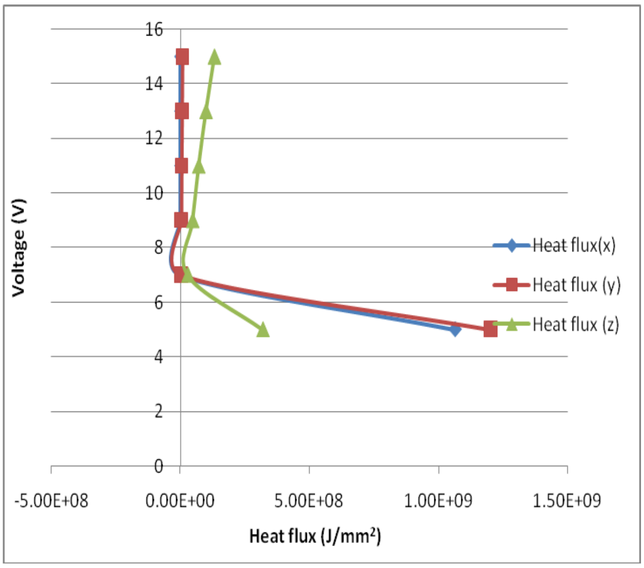

Figure-3.1:**Voltage vs. Heat flux**

The distribution of the thermal flux within the actuator at 15V is shown in Figure-3.5. The minimum and maximum values of Thermal flux -.192E+11and .157E+11 J/mm^2 at the actuator displacement of 27. 6189 µm. Similarly, the thermal gradients at 15V and 40°C are shown in Figure-3.6.The minimum and maximum values of Thermal gradients at 15V are -104.517 and 127.835at the actuator displacement of 27. 6189 µm.

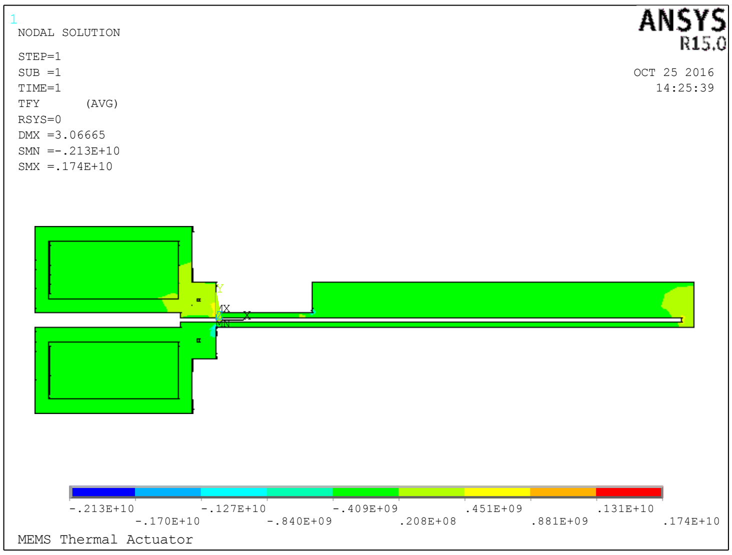

Figure-3.2: Thermal flux at 5V

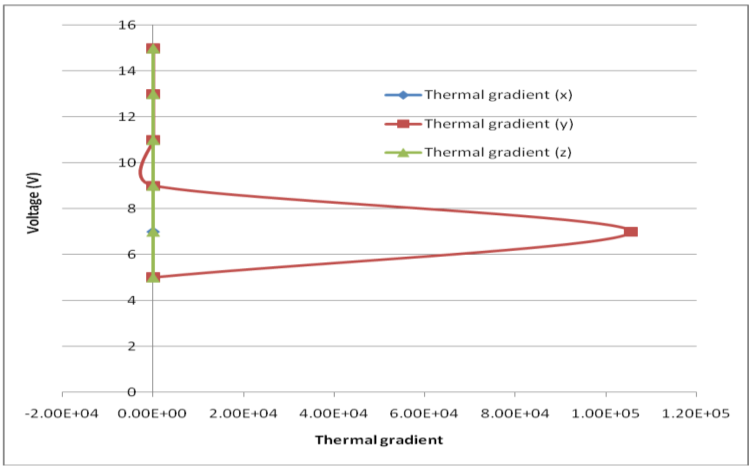

Figure-3.3: Voltage vs. Thermal gradient.

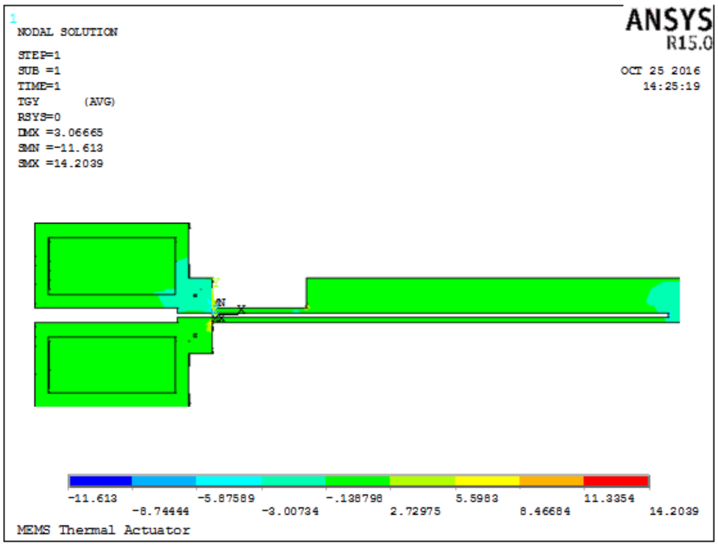

Figure-3.4: Thermal gradients in Y-direction at 5V

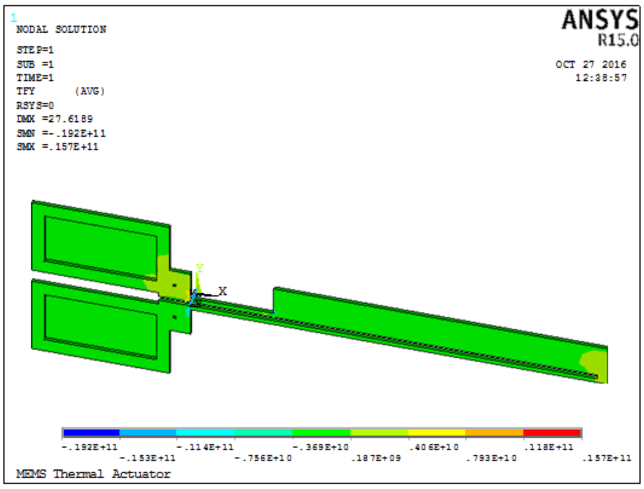

Figure-3.5: Thermal flux at 15V

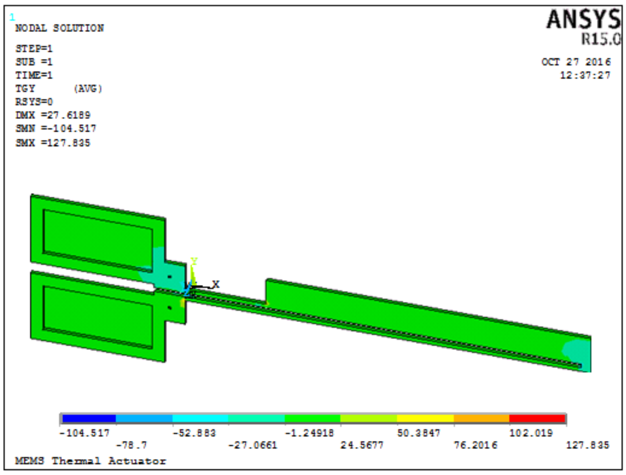

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Figure-3.6: Thermal gradients in Y-direction at 15V

Heat and Current:

The amount of current produced in the actuator as a function of applied voltage is shown in Figure-3.7. It is seen from the figure that the Voltage is varying in linearly with Current. Similarly, the amount of heat generated in the actuator as a function of applied voltage is shown in Figure-3.8. The Heat generated is gradually increasing with the applied voltage. The total heat flow is approximately 7.26e^{10} pW and the total current is approximately 9.68e^{9} pA.

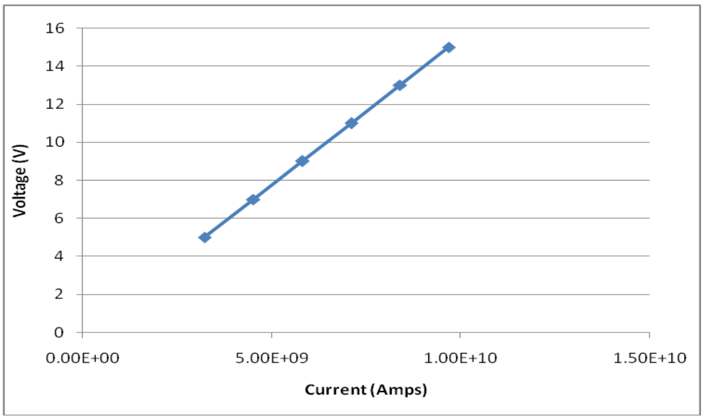

Figure-3.7: **Voltage vs. Current**

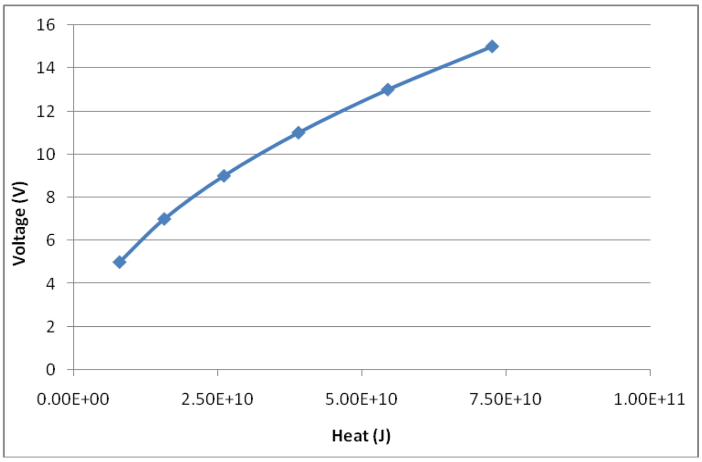

Figure-3.8:. **Voltage vs. Heat**

CONCLUSION:

Finite Element Analysis has been used for the simulation of thermal gradients and thermal fluxes generated in a MEMS actuator. ANSYS 15.0. a commercial software has been used for this purpose for three dimensional modeling. Simulation has been carried successfully and the results obtained for thermal gradients, thermal fluxes, Heat and Current produced due to a change in input voltage of the pads are compared and validated.

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