Finite Element Thermal Analysis of A Lateral Microelectro-thermal Actuators

MOHD SHUKHRI BIN ABD RAHMAN
Bachelor of Electrical Engineering (Hons.)
Faculty of Electrical Engineering
Universiti Teknologi MARA
Shah Alam,Selangor
Email: m.shukhri@yahoo.com

***Abstract*- This paper reports on the investigation to design, and characterize a lateral microelectro-thermal actuator using ANSYS in order to simulate. The aim was to compute and compare the blade tip displacement for an applied potential difference across the electrical connection pads, obtain the total current and heat flow performance of the differences material at the same operation conditions.**

Keyword – Microelectro-thermal actuator, ANSYS

I. INTRODUCTION

Actuators enable MEMS to perform physical functions and interact with their environments by altering geometries at the micron scale; they are the point at which energy is converted into force and motion. In many cases, an input signal is converted from the electrical domain to a non-electrical output signal in the radiant, magnetic, thermal, mechanical, or chemical domains.

Over the past years, different microelectromechanical systems (MEMS) actuators such as magnetic [1], electrostatic [2, 3] and electrothermal actuators [4, 5] have been well documented. Among the different actuation principles, the electrostatic actuation is predominantly employed for the electrostatic microactuators characteristics of simple structures, small energy loss and being compatible with integrated circuit processes [6]. However, electrostatic actuation mechanism has the disadvantages of high driving voltage and small displacement [7]; the high driving voltage has an adverse effect on the lifetime of devices [8].Therefore, electrothermal actuators attract much more research efforts because not only they can generate larger deflection and force, but also their fabrication process is very compatible with general IC fabrication process .

Common electrothermal methods of actuation include bimorph actuators (single and multi-material), bent-beam or chevron actuators, topology optimized structures, and various types of out-of-plane actuators. Thermal actuators have been applied to many different areas especially in space and radio frequency (RF) systems, particularly in the form of tunable capacitors .

II. WORKING PRINCIPLE AND GEOMETRY DESCRIPTION

The principle of actuation of microelectro-thermal actuator devices is described. The lateral actuator is sometimes referred to as a pseudo bimorph electrothermal actuator, or a heatuator.

Figure 1a gives a basic layout of the lateral microelectro-thermal actuator. As current passes through the series of beams, from one anchor to the other, the higher current density and Joule heating is greater in the long narrow “thin” arm beam as in Figure 1b $T_1 > T_2$. Since the “flexure” beam is much shorter and the “wide” arm beam much wider, the resistances and power consumption are much lower in these beams. The resulting temperature and thermal expansion in the thin arm beam is greater than the wide arm and flexure beams. Since the beams are connected at the free end furthest from the anchor points, a bimorph effect occurs and moves the free end in an arc in the plane of fabrication and approximately normal to the hot arm expansion direction. Therefore, as shown in Figure 1b, the narrow arm tends to expand more than the wide arm, and they achieve thermo-elastic equilibrium by bending toward the wide arm.

Its displacement is governed by thermal expansion resulting from heat dissipation, according to the heat equation written as [9]:

$$\frac{dE}{dt} = W - H; E = cT; W = RI^2 \quad (1)$$

in which E is the thermal energy stored in the microstructure, W is the power generated by Joule heat, and H is the heat transferred to the environment and substrate.

Overall, the basic design principle for the lateral microelectro-thermal actuator or pseudo bimorph actuator is to have one beam expand more than the other, in order to achieve motion at the free end.

In this paper, a lateral thermal actuator was introducing and overall length of the lateral actuator is 250-µm, and thickness of the beams are 2-µm respectively.

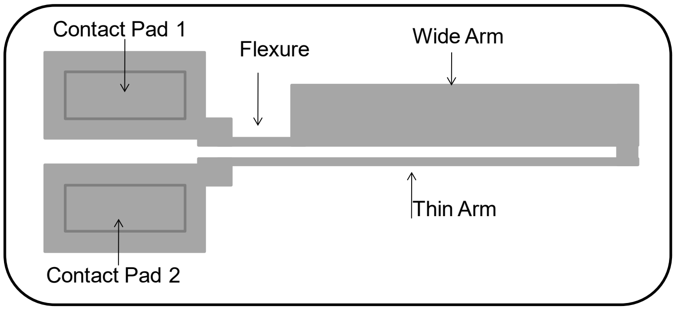

Figure 1a: The basic design of a lateral microelectro-thermal actuator.

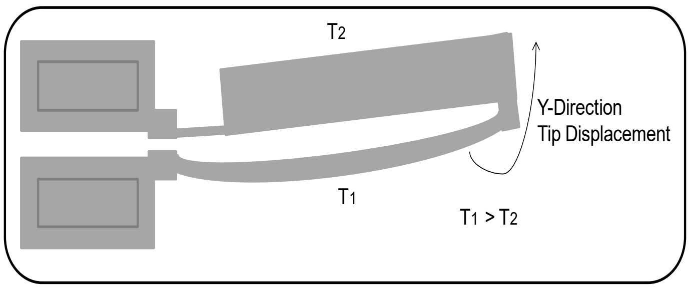

Figure 1b: Temperature in thin arm is higher than wider arm, causes it to heat and expand more than the wider arm.

II. Methodology

FEM analysis that is going to be discussed in this paper has been performed in ANSYS. Being it a multiphysical simulation tool, it is possible to couple different effects during the simulation flow. Figure 2 explain how ANSYS capabilities fits into a wide range of analytical software applications that are dedicated to assist in carrying out analysis and obtaining accurate numerical solutions of complex physical problems.

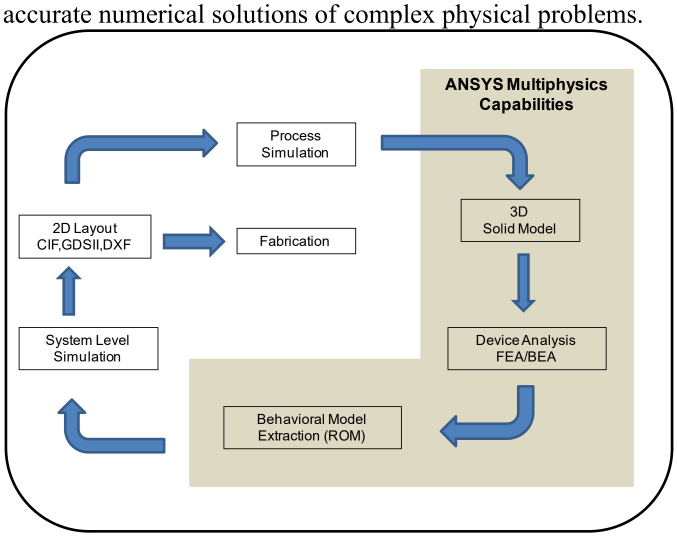

Figure 2. The design process flow in ANSYS

The structural-thermoelectric analysis in ANSYS also requires specifying several material properties; among them are Young's modulus, Poisson's ratio, thermal conductivity, coefficient of thermal expansion, electrical resistivity etc. The complete list of materials and their properties are reported in Tables 1. In this paper, SOLID92 and SOLID98 element in ANSYS element library are used for the lateral thermal actuator. For mechanical and nonlinear thermal-electric problems such as temperature and voltage degree could be solve using SOLID92 and SOLID98 respectively.

In modeling, multi-physics models including plane stress, conductive media dc and heat transfer (solid thermal conduction only) models were used. The heat losses by radiation, convection and conduction via air to the substrate were not considered in the simulation, as the aim was to compute and compare the blade tip displacement for an applied potential difference across the electrical connection pads, obtain the total current and heat flow performance of the differences material at the same operation conditions.

TABLE I
MATERIAL PROPERTIES

Material Properties	Polysilicon	Gold	Argentum	Cuprum	Nikel	Platinum	Palladium
Young's Modulus (Gpa)	169	79	83	110	200	168	121
Poisson's Ratio	0.22	0.44	0.37	0.34	0.31	0.38	0.39
Resistivity (nΩ·m)	23	22.14	15.87	16.78	69.3	105	105.4
Coefficient of Thermal Expansion (um/mK)	2.9	14.2	18.9	16.5	13.4	8.8	11.8
Thermal Conductivity (W/mK)	150	318	429	401	90.9	71.6	71.8

Generally, there are a number of parameter and option meshing shapes available in ANSYS for use during mesh creation. One of these is the smart size option that employs meshing rules to adjust the element density to the geometry of the model. For the model in this paper, the tetrahedral shapes elements are used.

IV. Results And Discussions

A. Smart Meshing Size

This software has provided an optimal meshing method to secure the accuracy of the simulation with an error of less than 0.1%. As can see in Figure 3a and 3b are the example of tetrahedral shapes with difference coarse mesh 2 and 10 respectively. The model for coarse mesh 2 has 10236 nodes and for coarse mesh 10 has 6395 nodes. As the mesh becomes more refined, the result become more accurate, but the simulation requires more time to complete the whole model.

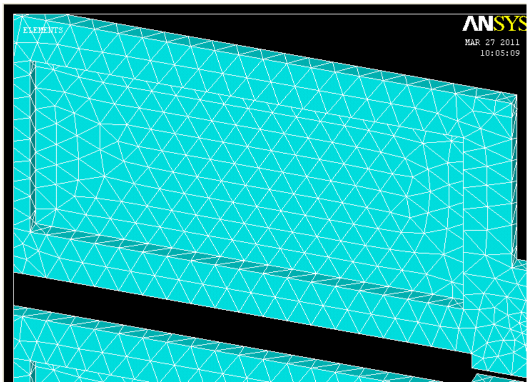

Figure 3a: Tetrahedral mesh refinement shapes when smartsizing control is equal to 2

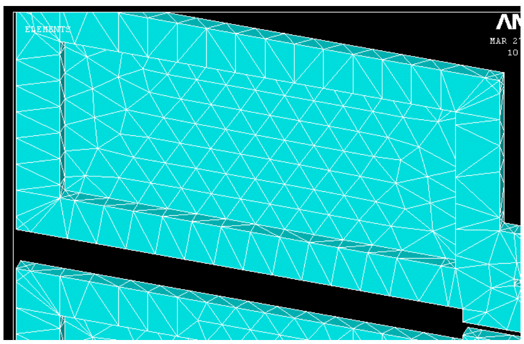

Figure 3b: Tetrahedral mesh refinement shapes when smartsizing control is equal to 10

Figure 4 shows simulated the lateral microelectro-thermal actuator using polysilicon as a material. With the potential voltage of 5V, its shows that the displacement difference between course mesh 2 and 10 only 0.77um. This make a good judgment to arrive at satisfactory results by using course mesh 10 for the next coming simulation.

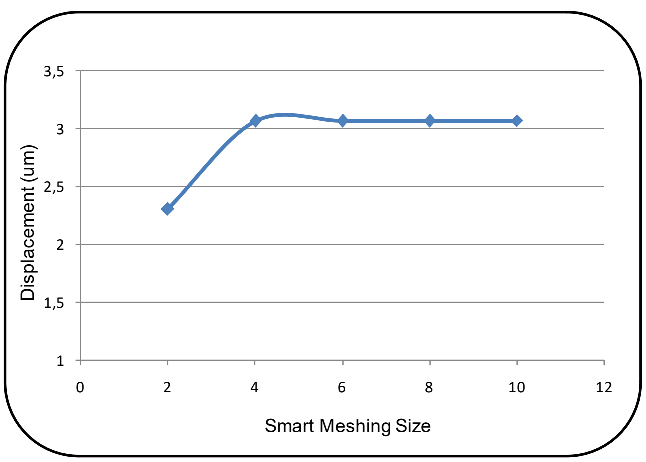

Figure 4: Simulated displacement for difference meshing size

B. Heat Flow

Figure 5a and 5b shows the numerical simulation of the actuator for Gold and Cuprum respectively. The maximum heat flow as a function of the input voltage is also provided in Figure 6. As shown in the figure below, all types of materials increase parabolically with increasing voltage. Argentum has maximum heat flow compare to others material which is 4.68e13 pW as compare to Polysilicon only 3.23 e10pW at 10V.

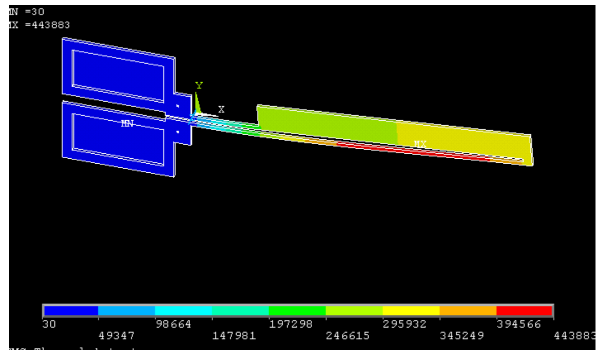

Figure 5a: Numerical result of heat distribution of Gold (Au) at 5V using ANSYS

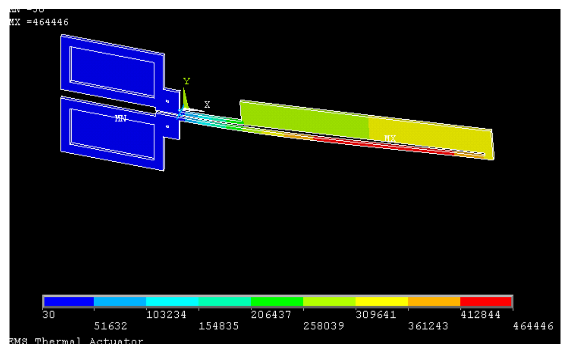

Figure 5b: Numerical result of heat distribution of Cuprum (Cu) at 5V using ANSYS

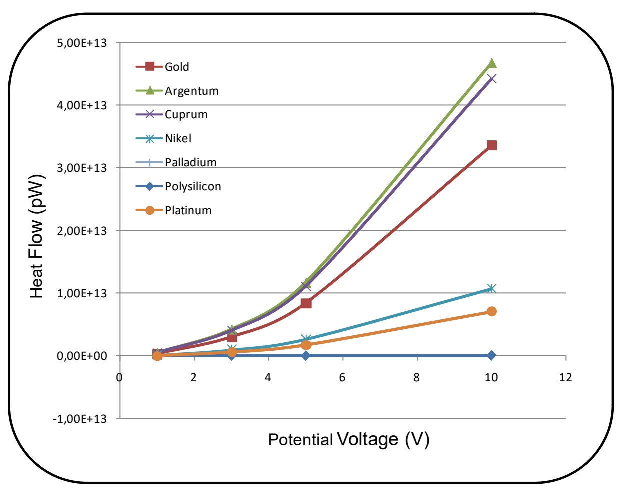

Figure 6 : Heat flow as a function of input voltage with different material property.

C. Current Flow

Figure 7 is a typical I–V characteristic of a device. At small voltage ranges, the current increases with voltage linearly and departs from it as the voltage increases further.

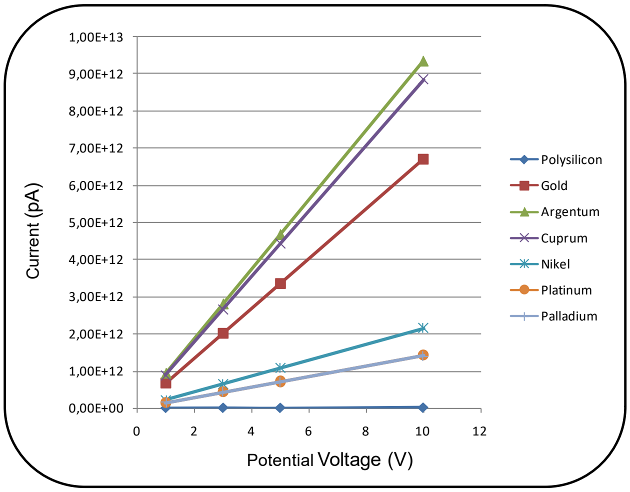

Figure 7: A typical *I–V* characteristic of a thermal actuator.

D. Tip Displacement

Figure 8a and 8b shows the displacement of the lateral actuator is parabolically to the potential voltage of the device. When the voltage start from 5V, the displacement increase linearly. The actuator from Argentum has the highest actuation heat, current and displacement.

.

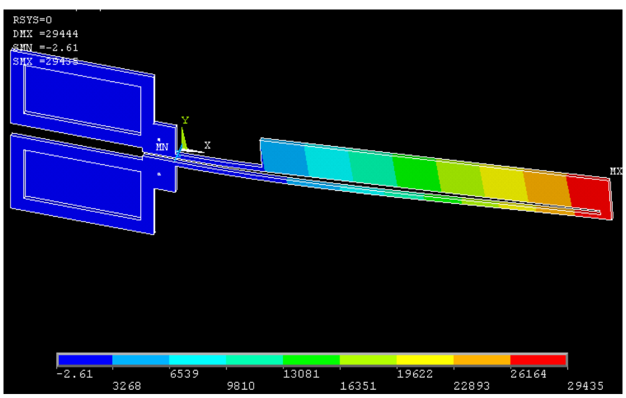

Figure 8a: Numerical result of deflection of Gold (Au) at 10V

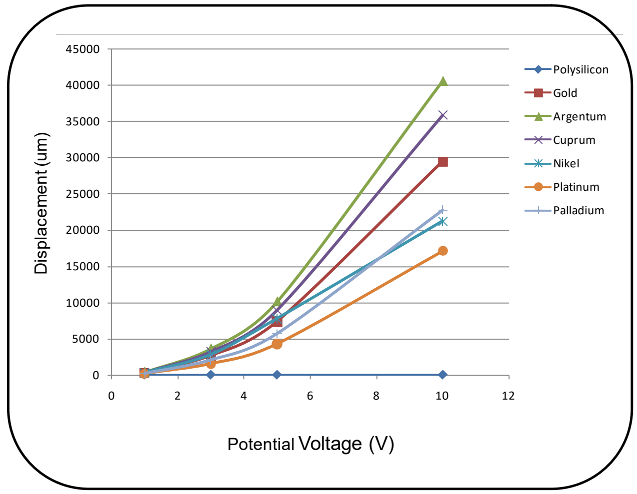

Figure 8b : Deflection of the tip of the lateral thermal actuator as a function of input voltage.

III. CONCLUSSION

Basic characteristics of the behavior of such lateral microelectro-thermal actuator were identified. The simulations reported here were performed with the best available data. It is important to note that a slightly different material property data will change the behavior of the devices slightly. However, with a suitable modification of the shape, the same performance for example displacement can be achieved with the new material property data. A further steps of study will be take into account about the size, shape, and topology which will determine the type of deformation, while material properties change only those deformations qualitatively.

ACKNOWLEDGMENT

First of all, would like to express my most gratitude to my supervisors, Pn. Anees bt Abdul Aziz and for the invaluable guidance, concerned, kindness, advice, comment, idea and helped to make sure of the successful of this project.

The would like to thank Faculty of Electrical Engineering UiTM for their technical advice and contributions.

Last but not least, also like to give thanks to my family, friends and colleagues for their supports, advices and comments.

REFERENCES

[1] C H Ahn and M G Allen, “A fully integrated surface micromachined magnetic microactuator with a multilevel meander magnetic core” J. Microelectromech. Syst. 2 15–22,1993

[2] T Yasuda, I Shimoyana and H Miura, “CMOS drivable electrostatic microactuator with large deflection Micro Electro Mechanical System” MEMS’97 10th Annual Int.Workshop (Piscataway, NJ: IEEE) pp 90–5,1997

[3] W C Tang, T C H Nguyen and R T Howe, “Laterally driven polysilicon resonant microstructures” Sensors Actuators A 20 25–32,1998

[4] J H Comtois and V M Bright, “Applications for surface-micromachined polysilicon thermal actuators and arrays” Sensors actuators A 58 19–25,1997.

[5] J H Comtois and V M Bright, “Vertical thermal acutators for micro-opto-electro-mechanical systems,” Proc. SPIE 3226 137–46,1997

[6] E. Thielicke and E. Obermeier, “Microactuators and their technologies”, Mechatronics 10 pp. 431–455,2000

[7] Poddar AK, Pandey KN. “Microwave switch using MEMS-technology.” In: Proceedings of the IEEE eighth international symposium on high performance electron devices for microwave and optoelectronic application,. p. 134–9. 2000

[8] Goldsmith C, Ehmke J, Pillans B, et al.,”Lifetime characterization of capacitive RF MEMS switc”. In: IEEE MTT-S international microwave symposium digest, Phoenix, AZ, , p. 227–302001.

[9] Dan 0. Popat, Byoung Hun Kangt, et al.,” Dynamic Modeling and Input Shaping of Thermal Bimorph MEMS Actuators”. lnternstionsl Conference on Robotics &Automation Taipei, Taiwan, September 14-19, 2003.