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Critical Analysis of Different Actuation Techniques for a Micro Cantilever

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Abstract**—**The objective of this work is to carryout critical comparison of different actuation mechanisms like electrostatic, thermal, piezoelectric, and magnetic with reference to a micro cantilever. The relevant parameters like force generated, displacement are compared in actuation methods. With these results, helps in choosing the best actuation method for a particular application. In this study, Comsol/Multiphysics software is used. Modeling and simulation is done by considering the micro cantilever of same dimensions as an actuator using all the above mentioned actuation techniques. In addition to their small size, micro actuators consume very little power and are capable of accurate results. In this work, a comparison of actuation mechanisms is done to decide the efficient system in micro domain.

Keywords**—**Actuation techniques, microswitch, micro actuator, microsystems.

I. Introduction

IN recent years, the Micro-Electro-Mechanical System (MEMS) technology is gaining importance because MEMS devices have superior sensing and actuating capabilities. Micro actuator converts energy into appropriate action capable of producing micron-scale motion for positioning individual elements in micro systems [1]. The various modes of actuation are electrostatic, electromagnetic, piezoelectric, and electro-thermal [2].

Electromagnetic actuation is based on the fact that a current-carrying conductor generates a magnetic field. If this conductor is a wire (or coil) and interacts with another external magnetic field (e.g. from a similar conductor or coil) a mechanical force is produced Magnetic actuation is used in the applications requiring high force or torque.

The fundamental actuation principle behind electrostatic actuators is the attraction of two oppositely charged plates. Their use is extensive in MEMS devices, since it is relatively simple to fabricate closely spaced gaps with conductive plates on opposite sides. For example, comb-drive-type actuators make use of a large number of fine interdigitated fingers that are actuated by applying a voltage between them. As the capacitance is related to area, the greater the number of fingers, the larger the force that can be generated by the actuator.

In piezoelectric actuation, the electrically induced displacement (or strain) is proportional to the applied potential difference. Larger displacements can be achieved using multiple piezoelectric layers known as piezoelectric bimorphs. Despite small displacements, relatively high forces (in the region of tens of MPa) can be achieved using lower voltages than those required for comparable electrostatic actuation. Most MEMS piezoelectric actuation is used where small strains are required (for example, the tip of a scanning tunneling microscope) [3]

A basic thermal actuation utilizes the difference in thermal coefficients for expansion of two bonded materials and it is referred to as thermal bimorph actuation [4]. Bimorph-thermal micro-actuators have been known as their large displacement and high force output. This characteristic is attributed by that static displacement generated from bimorph-thermal actuators is formed by net volume expansion due to the thermal expansion difference distributed over the whole actuator structure. Bimorph-thermal micro actuators have been intensively studied for wide applications such as accelerometers, actuators, angular rate sensors, optical switch [5].

II. Theoretical Background

A. Mechanical Actuator

For uniformly distributed load (UDL) or force per unit length, the deflection is (1):

$$x = \frac{Fl^3}{8EI} \quad (1)$$

where; F is the mechanical force, l is length of cantilever, I is moment of inertia, E is the Young's modulus of the material, x is the deflection at the tip.

B. Electrostatic Actuator

For a simplest parallel plate-type electrostatic micro actuator, the electrostatic force is created by applying a voltage across two plates that are separated by insulation layer with certain thickness. Electrostatic force generated is (2):

$$F = \frac{\varepsilon S V^2}{2d^2} \quad (2)$$

where; F is the electrostatic force, ε is the dielectric constant of the insulation material, V is the applied voltage, and d is the electrode distance between the two plates, S is the area of the plate [6].

C. Bimorph Thermal Actuator

The bi-material actuator obtains this effect by using two different materials with different coefficients of thermal

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expansion that are placed at the same temperature. The displacement of bimorph thermal bimorph actuator is (3):

$$\frac{1}{r}=\frac{6w_1w_2E_1E_2t_1t_2(t_1+t_2)(\alpha_1-\alpha_2)\Delta T}{(w_1E_1t_1^2)^2+(w_2E_2t_2^2)^2+2w_1w_2E_1E_2t_1t_2(2t_1^2+3t_1t_2+2t_2^2)} \quad (3)$$

where; w_1, w_2, t_1, t_2 are width and thickness of layer1 and layer2. E_1, E_2 Young's modulus of layer1 and layer2. α_1, α_2 are coefficient of thermal expansion of layer1 and layer 2 [7].

D. Piezoelectric Actuator

The tip deflection under a voltage of V in the case of unimorph micro cantilever is (4):

$$\delta(x)=\frac{3t_e(t_e+t_p)E_eE_px^2d_{31}V}{E_e^2t_e^4+E_eE_p(4t_e^3t_p+6t_e^2t_p^2+4t_et_p^3)+E_p^2t_p^4} \quad (4)$$

where; t_e and t_p is the thickness of the elastic and piezo film thickness, E_e and E_p is the Young's modulus of elastic and piezo materials, respectively. The d_{31} is the piezoelectric coefficient and V is the applied voltage.

E. Electromagnetic Actuator

Magnetic micro actuation is based on the electromagnetic effect, and force is created between the electric coil and magnet. The electromagnetic force along z direction is acting on the magnet (or coil) is calculated by (5):

$$F = BIL\sin\theta \quad (5)$$

where, θ is the rotation angle, I is current flowing through the coil, B is magnetic induction field, L is length of the coil, F is the electromagnetic force.

III. Modeling and Simulation Using COMSOL / Multiphysics

Modeling and simulation of the micro cantilever based actuator is done using the different actuation methods and with different materials. To analyze different actuation methods, the dimensions of the micro cantilever are considered as given in Table I. The schematic diagrams of the unimorph and bimorph cantilever are shown in Figs. 1 and 2.

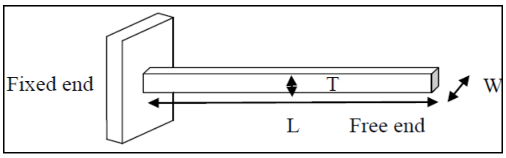

Fig. 1 Unimorph cantilever

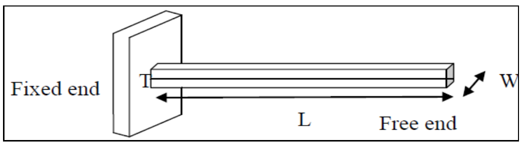

Fig. 2 Bimorph cantilever

TABLE I
DIMENSIONS OF THE CANTILEVER

Block	All dimensions in µm		
	Length	Width	Thickness
cantilever beam	100	10	2

Materials used in the modeling and simulations are mentioned in Table II. Two layered geometry or bimorph is used in case of the electro thermal, piezoelectric and electromagnetic actuation.

TABLE II
MATERIALS USED

Actuation method	Material-1	Material-2
mechanical	silicon	-
electrostatic	silicon	-
thermal bimorph	polysilicon	aluminum
piezoelectric	polysilicon	zno
electromagnetic	iron	aluminum

Actuation methods are defined by its input and output types. Various types of inputs and outputs for the particular actuation method are given in Table III.

TABLE III
INPUTS AND OUTPUTS FOR THE ACTUATION METHODS

Actuation method	Input	Output
mechanical	load	displacement
electrostatic	voltage	displacement
Thermal bimorph	temperature	displacement
piezoelectric	voltage	displacement
electromagnetic	magnetic flux conservation	displacement

A. Mechanical Actuator

Solid mechanics physics is used to model and simulate mechanical actuator. Silicon is used as the material. In this actuation method, one end of the cantilever is fixed. Load is applied on the surface of the cantilever so as to change its position. When there is change in the position of the cantilever based on the applied load, this can be used as the actuator. Simulated model of the mechanical actuator is shown in Fig. 3. Variations in the deformation with respect to the applied load in micro Newton is tabulated in Table IV.

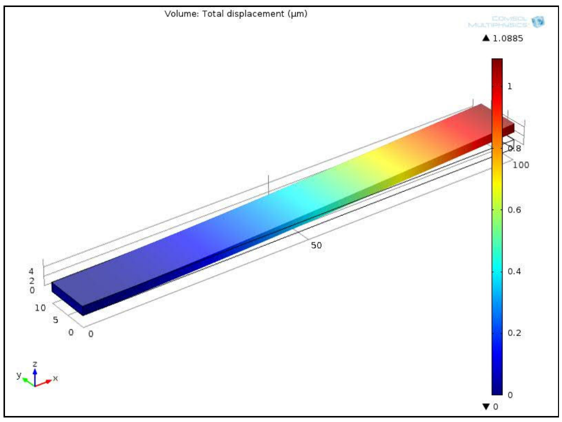

Fig. 3 Mechanical actuator

TABLE IV
LOAD V/S DEFORMATION IN MECHANICAL ACTUATOR

Load applied in µ Newton	Deformation (Simulated)	Deformation (Analytical)
1	0.1089	0.1114
2	0.2177	0.2228
3	0.3266	0.3312
4	0.4354	0.4416
5	0.5443	0.5888
6	0.6531	0.7065
7	0.762	0.8243
8	0.8708	0.9421
9	0.9797	0.1505
10	1.0885	1.1776

B. Electrostatic Actuator

Electro mechanics physics is used to model and simulate electrostatic actuator. In this actuation method, a cantilever and a contact electrode are used. Silicon is used as the material. Electric potential is applied to the cantilever and contact electrode is made as ground. Due to the presence electrostatic force between two plates, there is change in the position of cantilever is observed. Simulated model of the electrostatic actuator is shown in Fig. 4. Variations in the deformation with respect to the applied electric potential are tabulated in Table V.

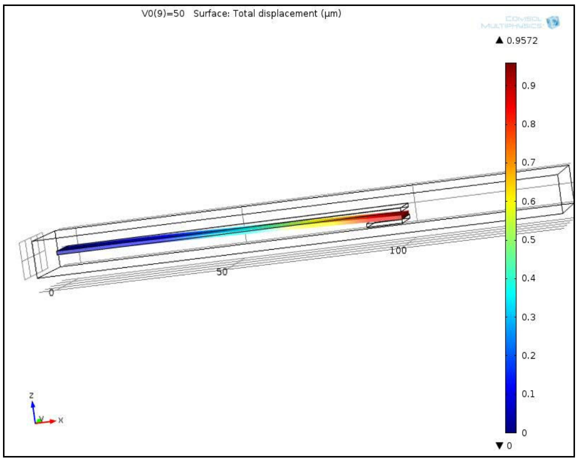

Fig. 4 Electrostatic actuator

TABLE V
VOLTAGE V/S DEFORMATION IN ELECTROSTATIC ACTUATOR

Voltage applied in voltage	Deformation (Simulated)	Deformation (Analytical)
20	0.0124	0.1302
30	0.0281	0.2929
40	0.0505	0.5208
50	0.0798	0.8137
60	0.1168	1.1718
70	0.1622	1.5950
80	0.217	2.0832

C. Bimorph Thermal Actuator

Joule heating and thermal expansion physics is used to model and simulate. In this actuation method, poly silicon and aluminum are used as the materials. Temperature is applied on the upper surface. Heat flux is applied to both layers. Simulated model of the bimorph thermal actuator is shown in Fig. 5. Variations in the deformation with respect to the applied temperature are tabulated in Table VI.

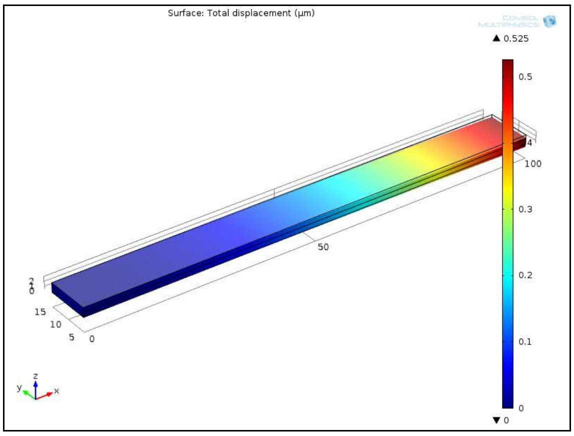

Fig. 5 Bimorph thermal actuator

TABLE VI
TEMPERATURE V/S DEFORMATION IN BIMORPH THERMAL ACTUATOR

Temperature applied in Kelvin	Deformation in micro meter
295	0.1418
300	0.525
305	0.9081
310	1.2913
315	1.6745
320	2.0577
325	2.4409

D. Piezoelectric Actuator

Piezoelectric device physics is used to model and simulate. In this actuation method bimorph cantilever is used.

Polysilicon and ZnO are used as the materials. Electric potential is applied to the upper surface and insulation layer is grounded. Simulated model of the piezoelectric actuator is shown in Fig. 6. Variations in the deformation with respect to the applied electric potential are tabulated in Table VII.

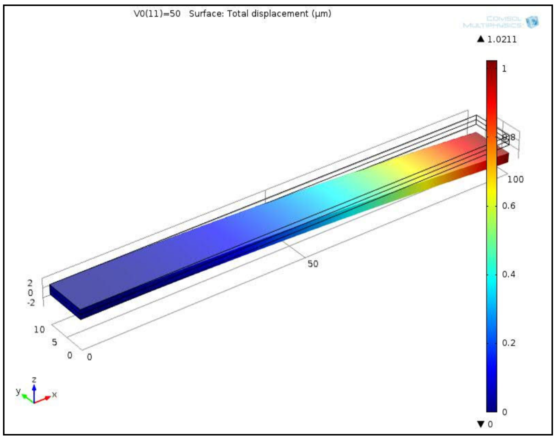

Fig. 6 Piezoelectric actuator

TABLE VII
VOLTAGE V/S DEFORMATION IN PIEZOELECTRIC ACTUATOR

Voltage applied in voltage	Deformation in micro meter
10	0.2042
15	0.3063
20	0.4085
25	0.5106
30	0.6127
35	0.7148
40	0.8169
45	0.919
50	1.0211

E. Electromagnetic Actuator

Magnetic fields, no currents physics is used to model and simulate. In this actuation method, bimorph cantilever is used. Iron and aluminum materials are used. Magnetic flux conservation is applied to the upper layer. Force calculation is selected to both layers. Simulated model of the Electromagnetic actuator shown in Fig. 7. Variations in the deformation with respect to the applied magnetic flux conservation are tabulated in Table VIII.

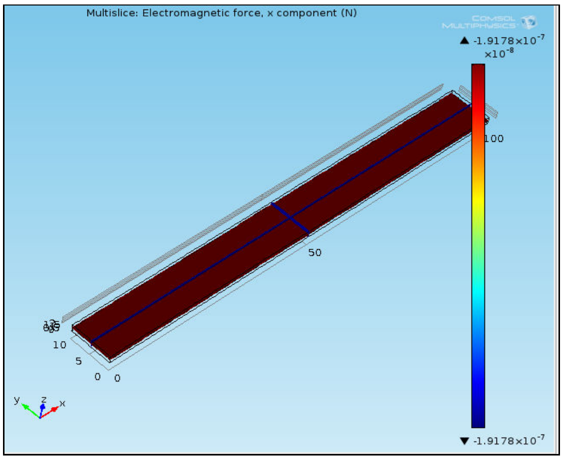

Fig. 7 Electro-magnetic actuator

TABLE VIII
MAGNETIC FLUX CONSERVATION V/S DEFORMATION IN ELECTROMAGNETIC ACTUATOR

Magnetic flux conservation (KA/m)	Deformation in micro meter
150	0.2157
200	0.3835
250	0.5993
300	0.8630
350	1.1746
400	1.5342
450	1.9417
500	2.397
550	2.9006
600	3.45

IV. RESULTS

Simulated results of different actuation method results are tabulated and analyzed. Simulated and theoretical values are compared in different actuation method.

V. CONCLUSIONS

Micro cantilever based on some actuation methods are modeled and simulated using the Comsol/Multiphysics software cantilever. All actuation results are compared with respect to displacement when the respective inputs are applied. These different actuation techniques have specific applications in different domains.

In future, this work can be extended to study the parameters like switching speed, power required, current for these actuation methods.

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. Anathasuresh, "Micromechanical devices with embedded electro-thermal compliant actuation", Proc. asme winter annual meeting volume mems-1, pp. 553-560, 1999.

[3] Prime faraday technology watch, "Introduction to mems (micro-electromechanical systems)", January 2002.

[4] Kovacs, g.t.a., *micromachined transducers sourcebook*, mcgraw-hill, New york, NY, 1998.

[5] M. S. Suen, j. C. Hsieh, K. C. Liu, david t. W. Lin, "optimal design of the electrothermal v-beam microactuator based on ga for stress concentration analysis"imecs, March 2011.

[6] B. G. Sheeparamatti, Prashant D. Hanasi, Kirankumar B. B, study of pull-in voltage in mems actuator" 2014 international conference on smart structures & systems (icsss-2014), Chennai, India.

[7] B.G. Sheeparamatti, Rachita Shettar "modeling and analysis of thermal bimorph using comsol" proceeding of the 2013 Comsol Conference in Bangalore.