Mahidur R. SARKER, Azah MOHAMED, Ramizi MOHAMED

Dept. of Electrical, Electronic & System Engineering, Faculty of Engineering & Built Environment, Universiti Kebangsaan Malaysia

doi:10.15199/48.2015.03.02

Performance evaluation modeling a Microelectromechanical system based Finite Element piezoelectric Shear Actuated Beam

Abstract*. This paper presents the modeling a Microelectromechanical systems (MEMS) based Piezoelectric shear actuated beam by using COMSOL Multiphysics software of version 4.3a. The overall dimensions model of the beam is of 0.1-m long, 0.03-m width and 0.018-m thickness. For this model the structural mechanics boundary conditions are of the cantilever beam is fixed at its surfaces at x = 0 and that all other surfaces are free. In this model applied, the different materials (i.e., Silicon, Titanium, Barium titanate, Lead zirconate titanate, Material) with voltages between the top and bottom surfaces of the piezoceramic domain (i.e., 15V, 35V) have been analyzed. Firstly, select the Structural Mechanics of the Piezoelectric Devices and analyzed changing the selecting physics. Secondly, defining the Geometry on deflection of sandwiched beam is setting the boundary condition and analyzed changing of the beam. Thirdly, the beam is composed of a 0.001-m thick flexible foam core sandwiched by two 0.002-m thick silicon and titanium layers. In the Fourth step, bend of beam is analyzed by changing both materials of sandwiched beam and mashing of the defection beam is display by changing both thickness and electric potential. Finally, the results of analysis allowed to conclude us to design a piezoelectric shear actuated beam with different ranges and resolutions, under the condition of changing both thickness and material of electrodes gives the optimum deflection of 0.0308-um and 0.0815-um under 15V input voltage with different materials.*

Streszczenie*. W artykule zaprezentowano metodę projektowania układów typu MEMS na przykładzie piezoelektrycznego siłownika. Dla siłownika zaproponowano model numeryczny oraz warunki brzegowe. Przedstawiono obliczenia dla różnych materiałów i różnych konstrukcji.* ***Modelowanie właściwości system MEMS na przykładzie siłownika piezoelektrycznego***

Keywords: Materials, Micro-devices, MEMS, Cantilever.
Słowa kluczowe: MEMS, siłownik pieszoelektryczny

.

Introduction

The development Micro-electro-mechanical systems (MEMS) technology is a capable for used to create small integrated devices or systems that combine mechanical and electrical components. The electronic devices are such as microelectronics low-loss, high linearity applications [1, 4] as well as the global interest in the concept of "piezoelectric beam". The topic of a model MEMS based piezoelectric Shear Actuated beam has received much attention with the recent growth. Over the past few years, micro cantilever has become so popular due to its high sensitivity selectivity, ease of fabrication and flexibility of on chip circuits. They are fabricated using integrated circuit (IC) batch processing techniques and can range in size from a few micro-meters to milli-meters. These devices (or systems) have the ability to sense, control and actuate on the micro scale, and generate effects on the macro scale [5]. Also it has become increase the popularity due to suitability to regulate, voluntarily deployable into integrated electromechanical system and does not require external detection devices [6-8]. Due to importance of this matter, many of researchers reported attempts on different aspects of Micro/Nano cantilevers and phenomena occurring around and a grandiose technical literature is available.

The idea behind this assumption is that in order to have phase delay in voltage distribution on the deflection of beam as an input. The use of the shear mode of piezoelectric materials has been investigated by [9-10]. The proposed architecture consists in a sandwiched beam for which part of the core has been replaced by piezoelectric material. The proposed configuration is such that, this time, the d15 coupling coefficient dictates the design. The electric field is applied perpendicularly to the poling direction, inducing a transverse shear strain. A finite element solution using sandwich beam has been proposed by [9-10] and compared to analytical results. Some studied on solid mechanics of the problem and developed theories on large deflection, size dependence, and higher order equilibrium etc, [11–13] some others discussed nonlinearities based on electrostatic. It occurs when the voltage exceeds a critical value in a way that the flexible micro/nano beam spontaneously deflects towards the substrate electrode.

This paper demonstrates the finite element method to obtain performance of Silicon, Titanium, Lead zirconate titanate (Pzt 7A) and Barium titanate (Poled) based micro cantilevers dimension and simulated MEMS based piezoelectric shear actuated beam by using COMSOL Multiphysics software of version 4.3a.

Modeling of MEMS Piezoelectric Shear Actuated Beam

Firstly, the work of this paper has been performed using the following design-flow as shown in Fig. 1. To do this work, the literature review was used to investigate on piezoelectric Shear Actuated Beam etc.

All the mentioned steps will be explained in details throughout the design and simulation steps on the coming sections.

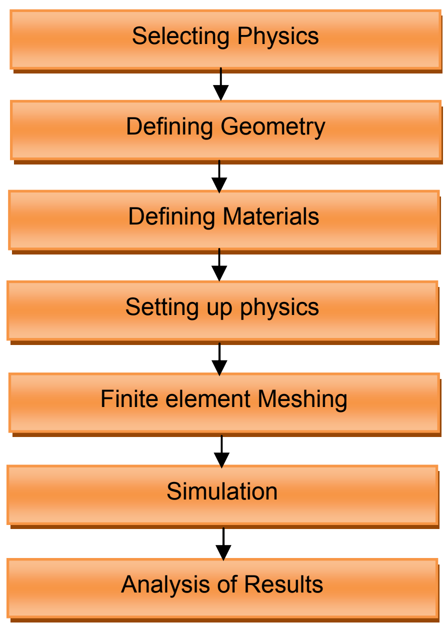


Fig.1. Flow chart of the design.

Selecting Physics

In the first step, piezoelectric devices present in structural mechanics module from the ADD PHYSICS tree and select the STUDIES in preset studies.

Geometry Modeling

The model consists of a 0.1-m long sandwiched cantilever beam. This beam is composed of a 0.02-m thick flexible foam core sandwiched by two 0.08-m thick silicon and titanium layers as shown in Fig 2. Further, the device replaces part of the foam core with a 0.01-m long piezoceramic actuator that is positioned between x = 0.55-m and x = 0.45-m. The cantilever beam is orientated along the global x-axis.

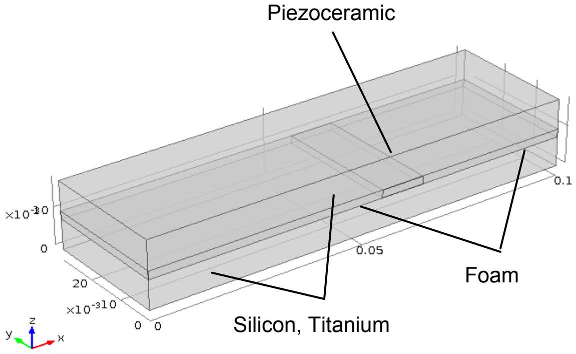


Fig. 2.Geometry of model.

Subdomain and Boundary Setting

Structural mechanics: The cantilever beam is fixed at its surfaces at x = 0; all other surfaces are free.

Electrostatics: The system applies a 15V, 25V and 35V electric potential on the Piezoelectric Devices difference between the top and bottom surfaces of the piezoceramic domain. This gives rise to an electric field perpendicular to the poling direction (x direction) and thus induces a transverse shear strain.

Material Properties of Piezoelectric Shear Actuated Beam

The following Table 1 gives the properties of materials used in the model:

Table 1. Property of material

Property	Silicon	Titanium (Ti)	Material	Lead zirconate titanate (PZT-7A)	Barium titanate (Poled)
Young's modulus	170e9[Pa]	115.7e9[Pa]	35.3e6 Pa	-	-
Poisson's ratio	0.28	0.321	0.383	-	-
Density	2329[kg/m^]	4506[kg/m^]	32 kg/m3	7700[kg/m^]	5700[kg/m^]

Silicon

Silicon is a chemical material has already changed the way think about electronics, this useful material is now in the process of altering conventional views of small mechanical devices and components. Bulk micromachining generally utilizes wet etching techniques to form three-dimensional structures in the silicon substrate. Silicon substrates, or wafers, are formed from large single crystal columns and it atomic number 14. Although wet bulk micromachining is currently the most prevalent technique used to create commercial MEMS products.

Titanium

Titanium is a chemical element with symbol Ti and atomic number 22. The high fracture toughness of titanium almost two orders of magnitude higher than silicon is often cited as one of its strongest attributes as a MEMS platform, and with good reason. In combination with its high ductility titanium devices can fail through yielding by plastic deformation rather than brittle fracture—often a detrimental yet unavoidable failure route for MEMS on silicon substrates.

A final note regarding titanium oxide: the fabrication of MEMS often requires electrical isolation from the substrate, and a titanium surface can be easily oxidized and at a much lower temperature than silicon, of particularly importance when critical yet thermally unstable components are part of the fabrication process.

Bariun titanate

Barium titanate is the inorganic compound with the chemical formula BaTiO3. It is a white powder and transparent as larger crystals. This titanate is a ferroelectric ceramic material, with a photorefractive effect and piezoelectric properties.

Barium titanate goes through two phase transitions that change the crystal shape and volume. This phase change leads to composites where the barium titanates have a negative bulk modulus (Young's modulus), meaning that when a force acts on the inclusions, there is displacement in the opposite direction, further stiffening the composite.

Lead zirconate titanate

Lead zirconium titanate is an intermetallic inorganic compound with the chemical formula Pb [ZrxTi1-x] O3 (0≤x≤1). Also called PZT, it is a ceramic perovskite material that shows a marked piezoelectric effect, which finds practical applications in the area of electroceramics. It is a white solid that is insoluble in all solvents. The two end components of the lead zirconate titanate phase diagram are lead titanate (PbTi0 3) and lead zirconate (PbZrC>3). At room temperature, PbTiC>3 is a ferroelectric ceramic with a tetragonally distorted perovskite structure, referred to as F t in the phase diagram. The tetragonal distortion of this phase, as indicated by the c/a ratio, decreases slowly with increasing temperature

Mashing

The mesh is composed of elements for a total number of degrees of freedom of 25476 have been built as shown in Fig 3. Then compute the model by and get displacement plot as follows: The same model can be simulate by changing voltages, materials and can observe for displacement plots.

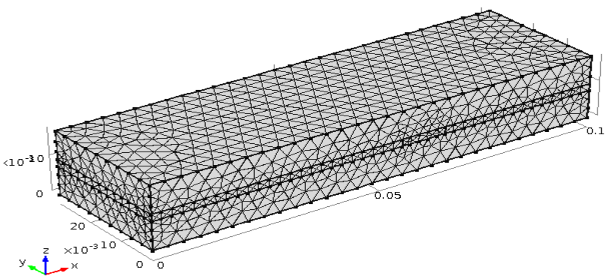


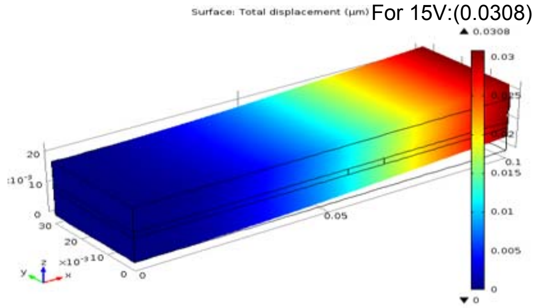
Fig. 3 Piezoelectric Shear Actuated Beam Mash.

Simulation Results of Developed Piezoelectric Shear Actuated Beam using COMSOL Multiphysics

Silicon and Pzt-7A Simulation-1

In this Silicon as electrodes and Pzt-7A piezoceramic material are taken and compute by applying 15V, 35V. The displacement plots are as follows shown in Fig 4:

For 15V:(0.0308)



For 35V:(0.0718)

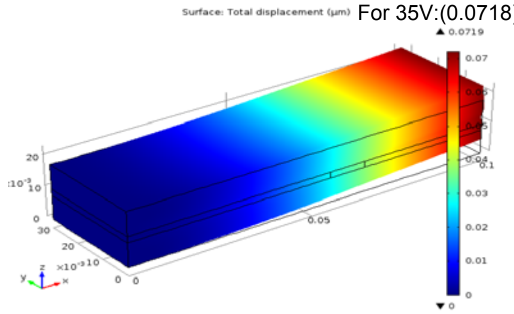
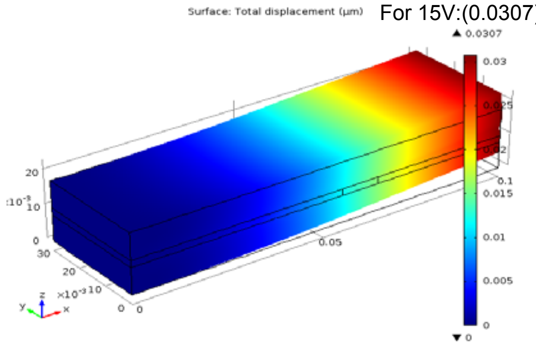


Fig. 4 Bend Beam plot for simulation-1

Titanium (Ti) and Pzt-7A Simulation-2

In this Titanium as electrodes and Pzt-7A piezoceramic material are taken and compute by applying 15V, 35V. The displacement plots are as follows shown in Fig 5:

For 15V:(0.0307)



For 35V:(0.0717)

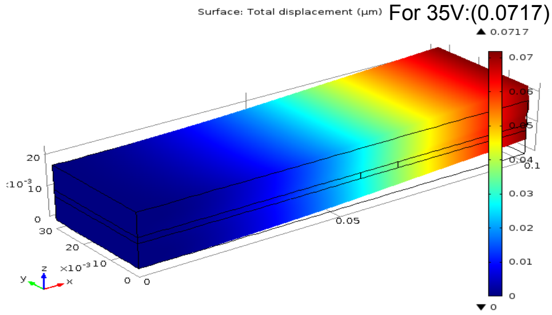
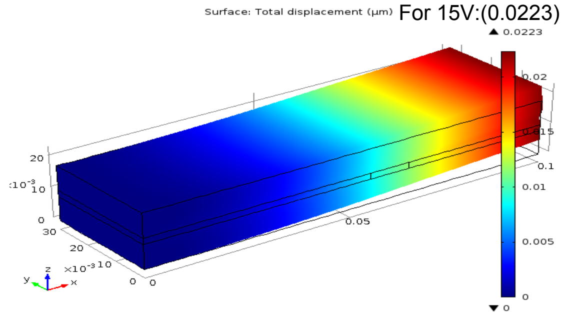


Fig. 5 Bend Beam plot for simulation-2.

Titanium (Ti) and Barium Titanate (Poled mat10) Simulation-3

In this Titanium as electrodes and Barium Titanate (Poled mat10) piezoceramic material are taken and compute by applying 15V, 35V. The displacement plots are as follows shown in Fig 6:

For 15V:(0.0223)



For 35V:(0.052)

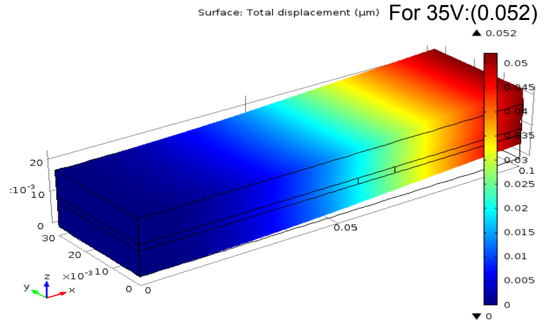
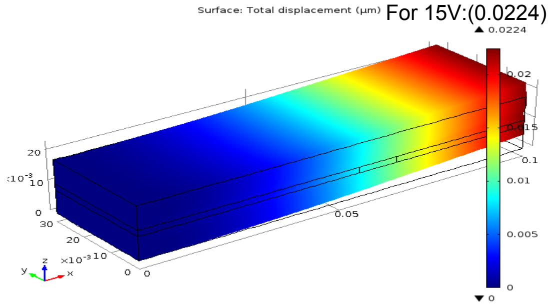


Fig. 6 Bend Beam plot for simulation-3.

Silicon (Si) and Barium Titanate (Poled mat10) Simulation-4

In this Silicon as electrodes and Barium Titanate (Poled mat10) piezoceramic material are taken and compute by applying 15V, 25V, 35V. The displacement plots are as follows shown in Fig 7:

For 15V:(0.0224)



For 35V:(0.052)

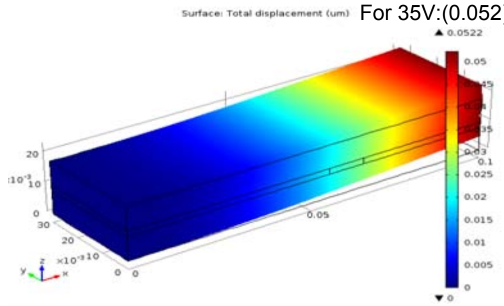
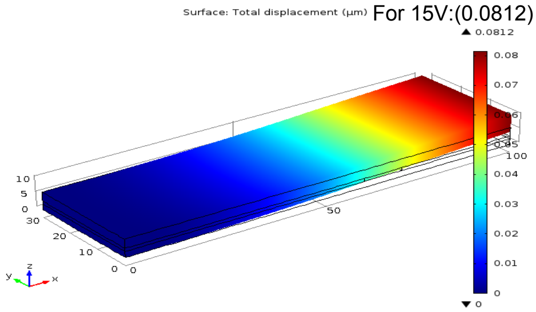


Fig. 7 Bend Beam plot for simulation-4.

Silicon (Si) with 2-mm Thickness and Lead Zirconate Tinanate (Pzt-7A) Simulation-5

In this Silicon with 0.002-m thickness as electrodes and Lead Zirconate Tinanate (Pzt-7A) piezoceramic material are taken and compute by applying 15V, 35V. The displacement plots are as follows shown in Fig 8:



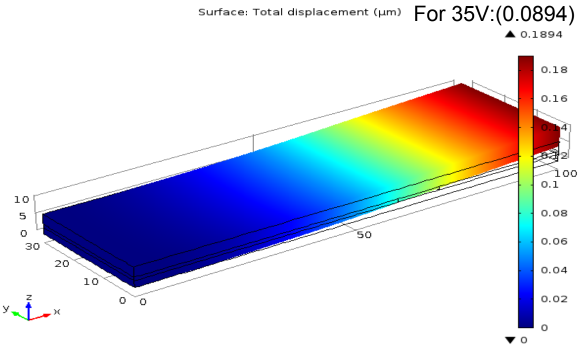


Fig. 8 Bend Beam plot for simulation-5.

Deflection beam voltage with different materials Simulation-6

The analyses from this simulation have been considered with different materials (i.e., Silicon, Titanium, Barium titanate, Lead zirconate titanate and Material) and compute by applying 15V. The displacement plots are as follows shown in Fig 9.

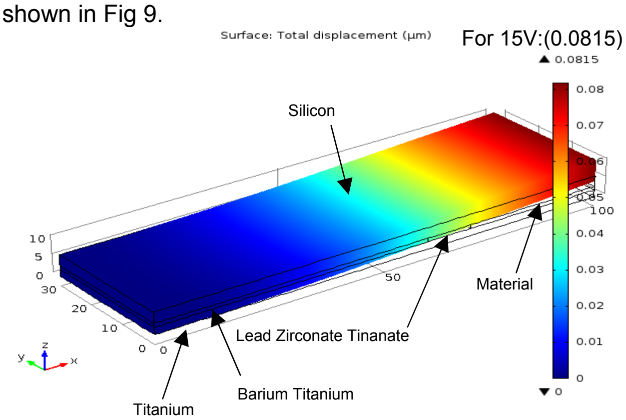


Fig. 9 Bend Beam plot for simulation-6 with different materials.

The analyses from the above simulation plot of those Figs it can be observed that as follows with increase in voltage the deflection of the beam is increases also with different materials but less than 5V the model becomes unstable. The piezoceramic material, lead zirconate titanate (Pzt 7A), Barium Titanate (Poled) gives high shear than any other piezoceramic material and also with decrease in the thickness of electrodes and using Silicon, Titanium high electrical conductivity material gives maximum shear in the beam.

Conclusion

This summarizes of this paper the simulation model for a piezoelectric shear actuated beam proposed and analyzed having 0.002-m thickness of silicon and titanium electrodes and 0.001-m thickness PZT-7A when apply than 15V gives deflection of the beam 0.0815-um but for the same model if apply less than 5V than the model become unstable compared the model 0.002-m thickness of PZT-7A when apply than 15V gives deflection of the beam 0.0308-um.

Acknowledgment

This work was carried out with the financial support from the Universiti Kebangsaan Malaysia *(UKM) under the research grant DIP-2014-028*.

REFERENCES

[1] Lifshitz, R. and M.L.,Roukes, Thermoelastic damping in micro and nanomechanical systems, *Physical review*. 6(2000), 5600-5609

[2] Roszhart, T.V., The effect of thermoelastic internal friction on the Q of micromachined silicon resonator, *Tech.Dig.Solid-State* Sens Actutaor Workshop,Hilton Head, SC. (1990), 13-16

[3] Vengallatore, S., Analysis of thermoelastic damping in laminated composite micromechanical beam resonator, *J.Micromech.Microeng*, (2005), 2398-2404.

[4] Zamanian, M. and S., E., Khadem, Mechanical & Aerospace Engineering Department, Tehran,Iran. Analysis of thermoelastic damping in microresonators by considering the stretching effect, *International Journal of Mechanical Sciences* (2010).

[5] Freeman, M., D., Micro electro mechanical systems. MEMS handbook edited by Mohammad Gad-El-Hak University of Notre Dame

[6] Thaysen, J. and A. Boisen, Atomic force microscopy probe with piezoresistive read out and a highly symmetrical Wheatstone bridge arrangement, *Sensors and Actuators*, 83(2000), 47–53

[7] Gotszalk, T., P., Grabiec, and I., W., Rangelow, Piezoresistive sensors for Scanning probe microscopy, *Ultramicroscopy*, 82(2000), 39–48

[8] Pinnaduwage, L. A., A., Gehl, D. L., Hedden, G., Muralidharan, T., Thundat, R. T., Lareau, T., Sulchek, L., Manning, B., Rogers, M., Jones and J. D., Adams, A microsensor for trinitrotoluene vapor, Nature, 425 (2003), 474

[9] Benjeddou, A., M. A., Trindade and R., Ohayon, A unified beam finite element model for extension and shear piezoelectric actuation mechanisms, *Journal of Intelligent Material Systems and Structures*, 8

[10] Benjeddou, A., M. A., Trindade and R., Ohayon, New Shear Actuated Smart Structure Beam Finite Element, 37(1999), 1-10

[11] Ahangar, S., G., Rezazadeh, R., Shabani, G., Ahmadi and A., Toloei, On the stability of a micro beam conveying fluid considering modified couple stress theory, *International Journal of Mechanics and Materials in Design*, 7(2011), 327–342.

[12] Yin, L., Q., Qian, L.,Wang and W., Xia, Vibration analysis of microscale plates based on modified couple stress theory, *Acta Mechanica Solida Sinica*, 23(2010), 386–393

[13] Ke, L. L. and Y., S.,Wang, Size effect on dynamic stability of functionally graded micro beams based on a modified couple stress theory, *Composite Structures*, 93(2011), 342–350

Authors*: Mahidur R. Sarker is a PhD student at the Department of Electrical, Electronic and Systems Engineering, Universiti Kebangsaan Malaysia (UKM), E-mail:sklobanrahman@yahoo.com.*
Prof. Dr. Azah Mohamed is a professor of Department of Electrical, Electronic and Systems Engineering, Universiti Kebangsaan Malaysia (UKM), E-mail: azah@eng.ukm.my.
Dr. Ramizi Mohamed is a senior lecturer of Department of Electrical, Electronic and Systems Engineering, Universiti Kebangsaan Malaysia (UKM), E-mail: ramizi@eng.ukm.my.