Calculation of Pull-in-Voltage for MEMS based Micro-Cantilevers using Piezoelectric Actuation

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***Abstract*—In MEMS, electromechanical elements are fabricated in the micrometer range. It deals with transducers which are a)Actuators and b)Sensors. In this paper we are focusing on actuator which provides mechanical movement in the device. Various types of cantilever beam structures are designed and their respective pull-in-voltages are being calculated using piezoelectric actuation technique. It decides which beam is more suitable to be used in switching applications. Due to the change in the cantilever length and the material used to design the cantilever, the pull-in-voltage changes. All the simulations are carried out in the Intellisuite software version 8.2.**

Keywords*— *MEMS; Piezoelectric actuation; cantilever; pull-in-voltage etc.

I. INTRODUCTION

MEMS(Micro-electromechanical systems) is a technology whereby various electrical and mechanical elements are fabricated in the micrometer range using two types of micro-machining processes like bulk and surface micromachining.

Cantilever is a mechanical structure which is used in various applications mainly in bio-sensing and as switches. The nature of the structure is such that one end is completely free, whereas the other end is clamped. In this paper various designs of cantilever are being considered and their pull-in-voltages are solved using the piezoelectric actuation technique for use as a switch.

Piezoelectricity is the effect found in some crystals, whereby they develop a certain potential on their surface as a result of pressure applied to them.

Pull-in voltage refers to that voltage till which a cantilever beam can restore their original position [2].

II. WORKING PRINCIPLE

Cantilever is the basic structure of micro-electromechanical system. Cantilever is the structure that is supported at one end and carries a load at other end along is length. This paper describes piezoelectric actuation as the actuation mechanism. For piezoelectric actuation, if we apply some voltage directly on the piezoelectric-material, then the material undergoes deformation. That is strain is produced in the material. Here the cantilever beam is fabricated with a piezoelectric material deposited near the clamped end of the structure to get the best results. The piezoelectric material used is PZT (Lead-Zirconate-Titanate) due to its various advantages over the conventional piezoelectric materials like quartz, Teflon and so on.

Figure 1 shows the piezoelectric actuation mechanism. As potential is applied on the piezoelectric material, the cantilever beam moves towards the lower reference plane.

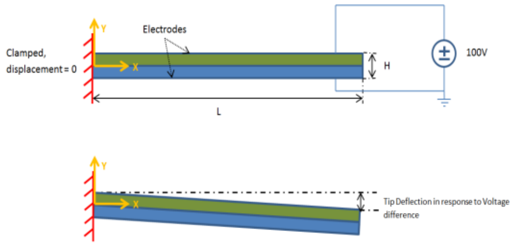

Fig. 1. A Piezoelectric actuation of cantilever structure

As we apply a DC voltage on the top-surface of the piezoelectric material and a zero DC voltage is applied to the beam, a potential difference is formed, as a result of which a force in the downward direction is originated. Therefore the gap between the piezoelectric cantilever beam and the lower reference plane diminishes due to the movement of the upper beam towards the lower plane.

As the piezoelectric beam reaches a position that equals to two-third of the original gap between the cantilever and the lower reference plane for a certain applied voltage, that voltage is called Pull-in voltage [5].

If the applied voltage is incremented further, the resulting force will become greater than the restoring elastic force and cause the upper beam to come in contact with the fixed ground plane and will short circuit the device like a switch. This is how the cantilever beam will be working as a switch using the piezoelectric actuation principle.

III. CANTILEVER BEAM STRUCTURES

The types of cantilever structures taken in this paper are as follows:-

1. Step-type Beam
2. Rectangular Beam
3. Proposed Beam

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Fig. 2. A Rectangular cantilever beam

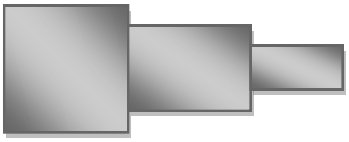

Fig. 3. A Step-type cantilever beam

Fig. 4. Proposed cantilever beam

The materials used to make the cantilever beam are tabulated below:-

Table 1: Material properties

Material	Poisson's ratio (constant)	Young's Modulus (GPa)	Density (g/cm3)
Pt	0.35	146.9	21.45
Ti	0.3	115	4.51
Au	0.42	74.48	19.32
Al	0.36	70	2.7

The different piezoelectric materials are as tabulated below:-

Table 2: Piezoelectric Material properties

Material	Form	Strain parameter (pC/N)
Quartz	Single crystal	2
PVDF	Polymer	20
Barium titanate	Ceramic	190
PZT	Ceramic	300-600
Zinc oxide	Single crystal	12
Lithium niobate	Single crystal	6-16

The dimensions of the cantilever can be altered by changing the length, width or thickness of the structure and by changing the air-gap between the upper beam and the lower plane.

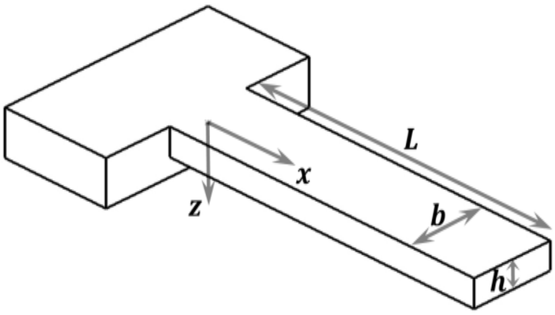

Fig. 5. A cantilever structure with proper labelling

IV. RESULTS

1. Rectangular Beam

When length=35µm, width=6µm, thickness=1µm and air-gap=0.5µm
Piezoelectric material is PZT of length=14µm, width=6µm and thickness=500nm

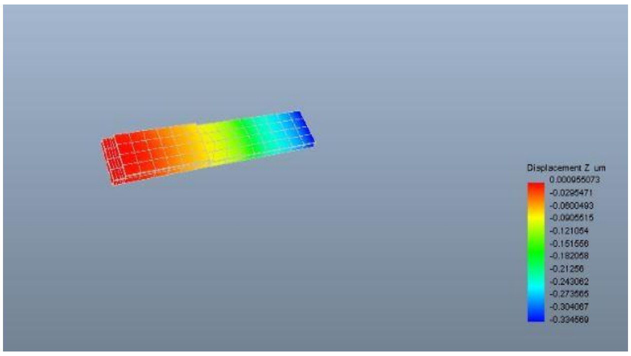

Fig. 6. Rectangular beam

Table 3: Rectangular beam with l=35µm

Material	Deflection (µm)	Potential (V)	Stress (Mpa)	Reaction Force (10^-6)N
Pt	5.69	-0.336742	65.67 to -172.3	18.5431
Ti	5.37	-0.335363	55.138 to -148.5	14.5117
Au	5.285	-0.336169	42.61 to -66.33	11.9376
Al	5.186	-0.335059	30.83 to -43.74	10.3986

Table 4: Rectangular beam with l=80µm

Material	Deflection (µm)	Potential (V)	Stress (Mpa)	Reaction Force (10^-6)N
Pt	2.18	-0.33920	31.651 to -69.72	2.797
Ti	2.1	-0.34468	25.83 to -59.92	2.31
Au	2	-0.34468	14.179 to -21.21	1.7003
Al	1.97	-0.33536	9.945 to -14.54	1.5492

In the table shown above it can be inferred that the dimensional as well as material changes leads to change in the pull-in-voltage. If the length of the cantilever beam is increased, the pull-in voltage will become low. So it simply means that pull-in voltage depends inversely on the length of the beam. The stress and reaction force profile is less in 1=80µm when compare to 1=35µm.

2. Step-type Beam

When length=35µm, width=6µm, thickness=1µm and air-gap=0.5µm

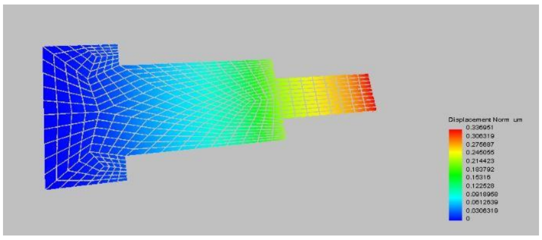

Fig. 7. Tapered beam

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Table 4: Step-type beam with l=35µm

Material	Deflection (µm)	Potential (V)	Stress (Mpa)	Reaction Force (10^-6)N
Pt	5.92	-0.33493	109.74 to -179.0	19.63
Ti	5.66	-0.337448	88.81 to -154.4	15.49
Au	5.48	-0.334248	49.635 to -57.44	12.72
Al	5.42	-0.335546	34.65 to -39.95	11.102

Table 5: Step-type beam with l=80µm

Material	Deflection (µm)	Potential (V)	Stress (Mpa)	Reaction Force (10^-6)N
Pt	2.26	-0.334719	41.78 to -68.15	7.4755
Ti	2.16	-0.337337	33.799 to -58.78	5.897
Au	2.13	-0.339584	19.24 to -22.24	4.9299
Al	2.084	-0.33757	13.288 to -15.3	4.2556

In the step-type beam structure, least pull-in voltage is shown by Aluminium (Al) material compared to others. The same arises in the case of rectangular beam, as length of cantilever is increased, the pull-in voltage is decreased. But the voltage is greater in step-type beam compared to the rectangular beam of same dimensions. The stress and reaction force is least for Aluminium (Al).

3. Proposed Beam

When length=35µm, width=6µm, thickness=1µm and air-gap=0.5µm

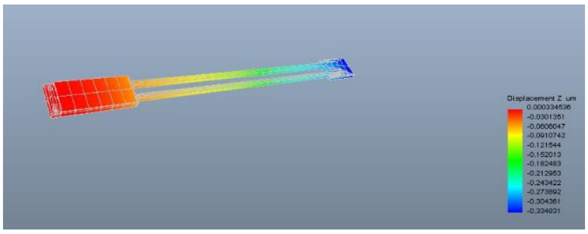

Fig. 8. Proposed beam

Table 6: Proposed beam with l=35µm

Material	Deflection (µm)	Potential (V)	Stress (Mpa)	Reaction Force (10^-6)N
Pt	5.57	-0.33536	102.46 to -195.7	18.667
Ti	5.28	-0.335161	82.11 to -165.86	14.952
Au	5.15	-0.336376	46.12 to -53.67	12.36
Al	5.07	-0.335862	32.088 to -37.03	10.42

Table 7: Proposed beam with l=80µm

Material	Deflection (µm)	Potential (V)	Stress (Mpa)	Reaction Force (10^-6)N
Pt	2.1	-0.336824	38.65 to -68.57	6.914
Ti	1.98	-0.33469	30.82 to -58.03	5.375
Au	1.94	-0.337099	17.41 to -20.19	4.463
Al	1.9	-0.33536	12.10 to -13.95	3.876

It can be observed that in the case of proposed beam the actuation voltage required is lesser compared to the other two cantilever beams. As a result we can conclude that this proposed beam is having giving the best result among these three structures. It can be therefore used as a switch. The pull-in voltage is best for the proposed structure made of Aluminium (Al).

V. CONCLUSION

Pull-in voltage is inversely proportional to the length of the cantilever beam, means it varies as there is change in dimension. If the cantilever has maximum length, it shows good result in terms of pull-in voltage. But we can't go on increasing the length just like that. The stress profiles are affected in such a case. Here the rectangular cantilever is having greater area compared to the step-type shaped cantilever. So the pull-in voltage is better for rectangular one. The length is found to have a greater effect than the width on the pull-in voltage.

Besides dimensions, another factor which affects the pull-in voltage is the material used to make the cantilever beam. Here Aluminium (Al) is comparatively better than other materials(Gold, Platinum and Titanium.The material having lesser value of Young's modulus of elasticity shows less pull-in voltage compare to other material. So we can observe that after Aluminium (Al), Gold, titanium and platinum are giving better results, repectively according to their Young's modulus value. If both material as well as dimensions are changed it leads to change in the pull-in voltage calculation.

The piezoelectric material used in this paper is PZT because of its high sensitivity compared to the other natural piezoelectric materials. A very small voltage is able to actuate the piezoelectric cantilever beam made of PZT. The main drawbacks of using PZT are its high cost and it contains lead in it so it can prove toxic which needs to be addressed. The results showed in this paper are better than the electrostatic actuation technique [4].

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