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Pull-In Voltage Calculation of Various Shaped Micro-Cantilevers

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***Abstract*—Microelectromechanical system (MEMS) is the technology of miniaturization. Micro Actuators are one of the MEMS components which provide movement in the device i.e. mechanically active. Now a days devices are getting smaller and smaller in size which affects the pull-in voltage. This paper helps in analyzing the different structure of cantilever based on electrostatic actuation and also help in deciding which cantilever structure is good for the application. These cantilevers can be used as a switch in many applications. This paper presents the change in pull-in voltage with the change in length, width, thickness, gap & material property. Simulation has been carried out using Intellisuite software version 8.6.**

***Index Terms*—Cantilever, Pull-in voltage, Young's modulus etc.**

I. Introduction

Microelectromechanical system is a technology used to define the miniaturized mechanical and electromechanical element and as it is define in micro scale that's why it is called as Microelectromechanical system (MEMS).

Cantilever is horizontal beam with one end fixed and other end free or flexible [5]. Every structure has so many parameters such as Pull-in voltage, stress, reaction force, current, temperature etc. This paper mainly focused on Pull-in voltage of the shaped cantilever. This type of cantilever mainly realized as switch. The drive mechanism of cantilever beam includes a constant voltage source to enable electrostatic actuation or capacitive actuation.

Pull-in voltage is the voltage or a point in the range of voltage up to which any beam can attain their previous position [3].

II. Basic Principle

Cantilever is the basic structure of microelectromechanical system. Cantilever is the structure that is supported at one end and carries a load at other end along is length. This paper describes electrostatic actuation as the actuation mechanism.

Figure 1 shows the electrostatic actuation mechanism where one plate is fixed and the other plate acts as cantilever with one end fixed and other end free. As potential difference is created between the two plates, the upper plate move towards the lower plate [1].

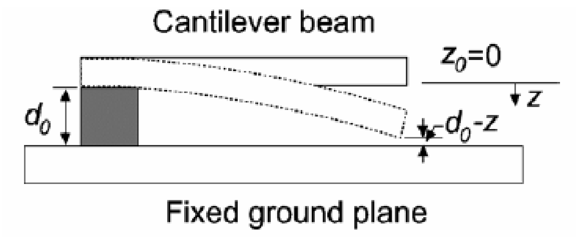

Figure1. Geometric model of cantilever

The basic principle behind electrostatic actuation is the attraction of two oppositely charged plates. When a DC voltage is applied across the plates causes an electrostatic pull-down force and consequent reduction of the air gap, resulting in change in capacitance. Thus, micro-cantilever beams can act as a variable capacitor.

A voltage is applied at both the beam i.e. upper and lower beam, an electrostatic force is generated which pushes upper plate (flexible plate) towards lower plate (fixed plate). When upper beam reaches a position that corresponds to 2/3 of the original gap between the beam and the fixed electrode that point is called Pull-in voltage. If the applied voltage increased beyond the pull-in voltage, the resulting force will overcome the elastic restoring force and will cause the movable plate to collapse on the fixed ground plane and the device will be short circuited. This phenomenon is known as pull-in voltage [4].

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III. VARIOUS CANTILEVER BEAM STRUCTURE

This paper discussed three different structures of micro cantilevers.

1. Rectangular Beam
2. Center Fixed Beam
3. Tapered V- Shaped Beam

Figure 2. Rectangular Beam

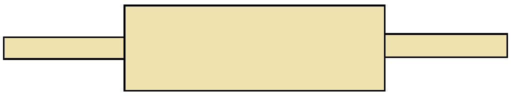

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Figure 3. Center Fixed Beam

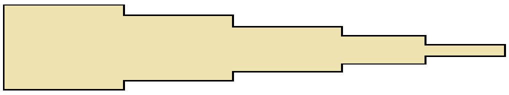

Figure 4. Tapered V-Shaped Beam

These three structures are analyzed on the basis of various types of

1. Materials
2. Dimensions of the structures

Every material has their own properties like Young's modulus, poison ratio, density etc.

Table I: Properties of Different Material

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

Dimensions of the structures can be varied by length, width, thickness and the gap between both the plates etc.

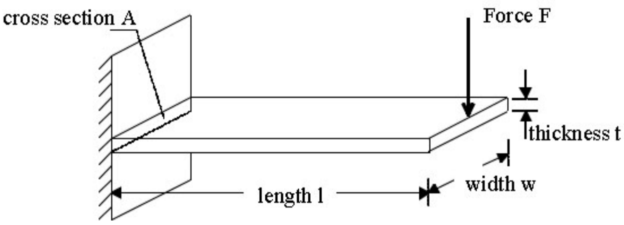

Figure 5. Cantilever Structure with Labling

IV. RESULTS

A. Rectangular Beam

When length=35µm, width=5µm, thickness=1µm, gap between the plates=1µm

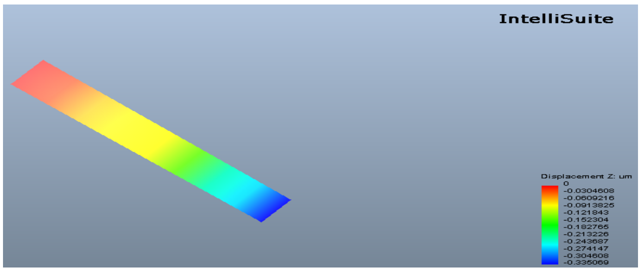

Figure 6. Rectangular Beam

Table II: Rectangular beam with l=35µm

Material	Voltage	Displacement (µm)	Stress (MPa)	Reaction Force (10^-6)N
Au	42	-0.336102	69.9316 to -50.2599	19.6426
Pt	58.85	-0.335635	107.714 to -56.8984	24.7171
Ti	51.5	-0.332950	75.4957 to -31.5583	14.2899
Al	40.7	-0.335069	52.3933 to -39.0629	12.492

Table III: Rectangular beam with l=80µm

Material	Voltage (V)	Displacement (µm)	Stress (MPa)	Reaction Force (10^{-6})N
Au	7.8	-0.330563	13.4241 to -9.67082	2.0834
Pt	10.85	-0.332174	20.730 to -11.0421	2.65573
Ti	9.55	-0.331346	14.6131 to -6.16904	1.54981
Al	7.5	-0.332526	10.1475 to -5.65235	1.34438

The above tables indicate the pull-in voltage variation as dimensions changes. As there is increase in length, the pull-in voltage will reduce. It means pull-in voltage further reduces as we increase the length of the beam. It indicates that length is inversely proportional to pull-in voltage. Also stress and reaction force is less in l=80µm when compare to l=35µm.

B. Center Fixed Beam

When length=35µm, width=5µm, thickness=1µm, gap between the plates=1µm

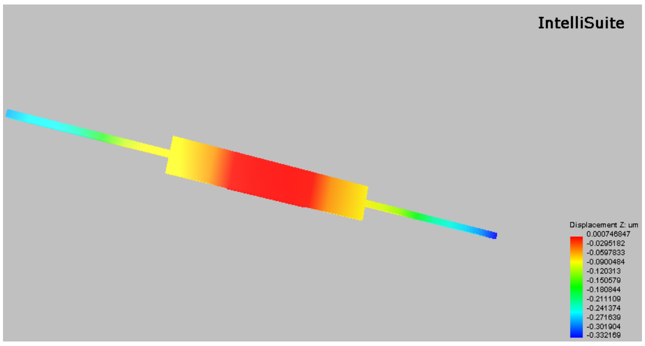

Figure 7. Center Fixed Beam

Table IV: Center Fixed Beam with l=35µm

Material	Voltage (V)	Displacement (µm)	Stress (MPa)	Reaction Force (10^{-6})N
Au	19480	-0.335536	1035.02 to -73.0461	1637.91
Pt	27500	-0.335813	2183.15 to -14.4248	3272.92
Ti	24250	-0.335086	1753.26 to -159.387	2545.13
Al	19000	-0.336385	1035.12 to -12.6739	1562.34

Table V: Center Fixed Beam with l=80µm

Material	Voltage (V)	Displacement (µm)	Stress (MPa)	Reaction Force (10^{-6})N
Au	12000	-0.33649	421.622 to -94.7958	252.35
Pt	16700	-0.334688	901.21 to -2.66859	488.749
Ti	14750	-0.338434	732.16 to -0.10266	381.279
Al	11500	-0.332169	422.905 to -1.53056	231.763

In the Center Fixed beam structure, Aluminium material shows less pull-in voltage as compare to any other material. The same arises in the case of rectangular beam, as length of the beam increases, pull-in voltage decreases. But the voltage is very high in compare with the rectangular beam of same dimensions. Center Fixed beam pull-in voltage is in kilo-volt (kV) whereas in rectangular beam it is in volt (V) only. Also reaction force is less in case of Aluminium material from rest of the materials.

C. Tapered V-Shaped Beam

When length=35µm, width=5µm, thickness=1µm, gap between the plates=1µm

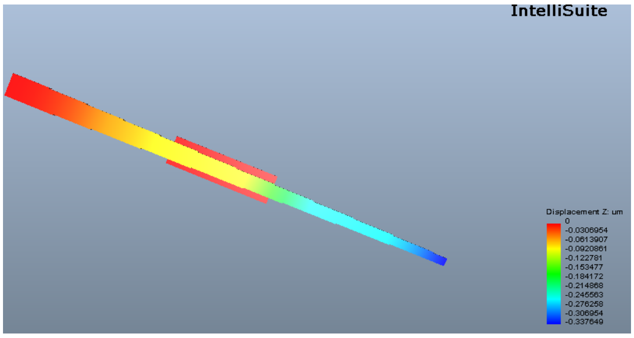

Figure 8. Tapered V-Shaped Beam

Table VI: Tapered V-Shaped Beam with l=35µm

Material	Voltage	Displacement (µm)	Stress (MPa)	Reaction Force (10^-6)N
Au	163	-0.33375	82.7663 to -59.52	10.1923
Pt	225	-0.334425	140 to -74.6461	13.084
Ti	198	-0.337042	102.707 to -43.4474	7.67437
Al	156	-0.335739	68.2977 to -38.02	6.65027

Table VII: Tapered V-Shaped Beam with l=80µm

Material	Voltage (V)	Displacement (µm)	Stress (MPa)	Reaction Force (10^{-6})N
Au	17.3	-0.33976	12.1065 to -8.70293	0.543238
Pt	24	-0.333398	19.8538 to -10.5673	0.708505
Ti	21.25	-0.336925	14.6297 to -6.18695	0.425043
Al	16.65	-0.337649	9.75012 to -5.42378	0.361264

In Tapered V-shaped structure, the beam made up of aluminum material has very less pull-in voltage when compared to other materials in both the dimensions. Also in dimension wise, beam with maximum length shows good in pull-in voltage.

V. CONCLUSION

This paper deals with the pull-in voltage of micro cantilevers. The pull-in voltage of various micro cantilevers varies with the change in material and dimensions.

Pull-in voltage is inversely proportional to area means it varies as there is change in dimension. The beam which has maximum area shows good result in pull-in voltage. Here rectangular beam shows maximum area when compared to other shaped cantilevers. The length found to have a great influence on the pull-in voltage. As there is increased in length, pull-in voltage will drastically decrease.

On the other hand, different types of material are also affecting the pull-in voltage. Here Aluminium shows comparatively better result than any other material (Gold, Platinum and Titanium). Material properties are different for different materials. Here Aluminium has very less Young's modulus as compare to other material. It means that the material whose Young's modulus is less shows less pull-in voltage compare to other material. Next Gold shows better result and the result is comparatively near to the Aluminium material. Platinum and Titanium materials have very high Young's modulus so it shows high pull-in voltage in compare to other two materials i.e. Aluminium and Gold. It means that the material whose Young's modulus is less shows better result in case of pull-in voltage when compare to other materials having high Young's modulus. Both material as well as dimensions affects the pull-in voltage calculation.

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