ANALYSIS OF CANTILEVER BEAM BASED ELECTROSTATIC MEMS SWITCH USING SILICON CARBIDE AND GRAPHENE MATERIAL

Vijay Mallappa Peerapur[a], Anilkumar V Nandi[b].
[a] Dept. of ECE, Government, Engineering College, Haveri 581110
[b] Dept. of ECE, KLE Technological University, Hubbali 580031

Abstract: This paper describes the pull-in Voltage study and Analysis of Cantilever Beam based MEMS Switch with Electrostatic Actuation. Graphene and Silicon Carbide are used as Cantilever Beam Material. COMSOL Simulation is performed for the Cantilever beam using Electrostatic actuation. Because of the material Properties of Silicon Carbide and Graphene, the reliability of the MEMS Switch could be improved. The Pull-in Voltage of Silicon Carbide and Graphene based Cantilever beam are 46.275 volts and 30.9125 volts respectively. With Perforations, The pull-in Voltage is found to be 26.225 volts and 39.0375 volts for Silicon Carbide and Graphene cantilever beam respectively.

Keywords: Pull-in Voltage, Cantilever Beam, Electrostatic actuation

1. INTRODUCTION

The PIN diode and FET switches are been replaced by Electrostatic Microelectromechanical Systems (MEMS) Switches because of high isolation, low insertion loss, low power consumption, high cut-off frequency. The RF MEMS Switch contains two parts namely a Mechanical Section and an Electrical section. Mechanical Movement can be obtained using either electrostatic, magnetostatics, piezoelectric, or thermal forces. MEMS Switch can be connected in either series or shunt Configuration. Electrostatic actuation is mostly used because of the small size [1-2].

Silicon Carbide is characterized by high thermal Conductivity, High electrical breakdown strength, Wide bandgap and stability at elevated temperatures, and chemical inertness. These properties of SIC lead to the improvements in Reliability, higher Power handling capability and operating frequency of RF MEMS Devices[3,4].Silicon Carbide switches are used for High Voltage Applications [4].

The electricity conductivity of Graphene is much better than the gold and copper wires used in current devices. Graphene has high thermal conductivity, ultrahigh stiffness and strength, and hydrophobic surface [5].

2. THEORETICAL UNDERSTANDING

When the electrostatic actuation voltage is applied to the cantilever beam. The Electrostatic force will bring the beam and ground closer. As the bias voltage increases, the gap between the beam and ground decreases. At pull-in Voltage, electrostatic force over comes the mechanical restoring force resulting in cantilever beam become unstable and beam collapses [6,7].

The Pull-in Voltage expression [8] for a cantilever beam is given by Equation (1)

$$Vp = \sqrt{\frac{8kd^3}{27\varepsilon A}} \tag{1}$$

where k is spring constant, d is gap between electrode and the beam, A is area of electrode and ε is permittivity of area.

The expression for the Spring Constant [8] k is given by Equation (2)

$$k = \frac{2\left(\frac{E}{1-\nu^2}\right)wt^3}{3l^3} \tag{2}$$

where k is the spring constant, E is the young's modulus , w is the width , t is the thickness and l is the length of the beam and ν is the Poisson's ratio.

The Geometry of the Cantilever beam with Anchor is shown in Figure 1. and Cantilever Beam dimensions are shown in Table I.

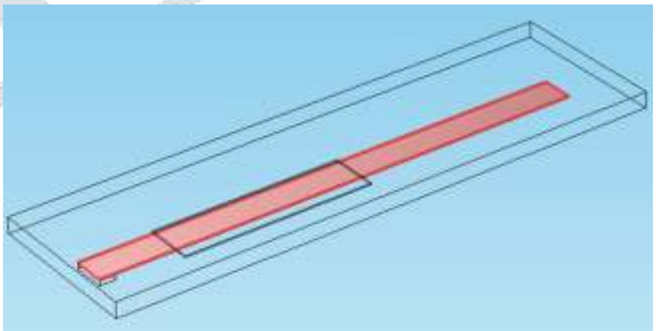

Figure 1. Geometry of Cantilever Beam with Anchor and Electrode.

Table 1. Cantilever Beam Dimensions

Parameters of Cantilever	Units (µm)	Description
Length	300	Length 300 µm
Width	20	Width of 20 µm
Thickness	1.5	Thickness 1.5µm

3. SIMULATION AND RESULTS

The Simulation is performed using COMSOL Multiphysics for Silicon Carbide and Graphene Material based Cantilever Beam.

The Simulation of the Cantilever beam is performed with and without perforations. The Pull-in voltage could be reduced by reducing the spring constant, reducing thickness of the cantilever beam and by reducing the gap between the cantilever and electrode by looking at Equations (1) and (2).

Perforations are performed on the Cantilever beam to reduce the actuation Voltage.

3.1 Graphene based Cantilever beam

The Displacement of the Cantilever beam for different actuation voltage and Cantilever Tip displacement at 46.275 volts for Graphene based cantilever beam is shown in Figure 2. and Figure 3. respectively.

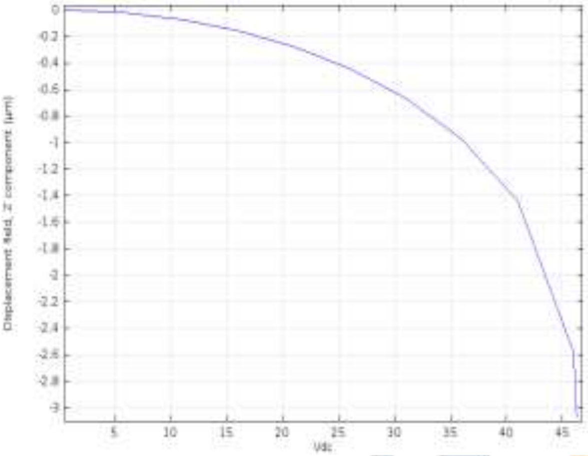

Figure 2. Graphene based Cantilever beam displacement for different bias voltage.

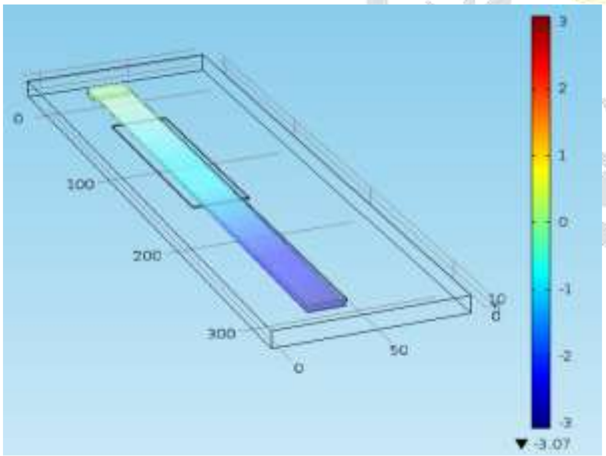

Figure 3. Graphene based Cantilever beam Tip Displacement in the Z-direction.

Figure 2. shows that for applied voltage higher than 46.275V, the cantilever beam becomes unstable.

3.2 Graphene based Perforated Cantilever Beam

The Displacement of the perforated Cantilever beam for different actuation voltage and Cantilever Tip displacement at 39.0375 volts for Graphene based perforated cantilever beam is shown in Figure 4. and Figure 5. respectively.

Figure 4. shows that for applied voltage higher than 39.0375 volts, the cantilever beam becomes unstable.

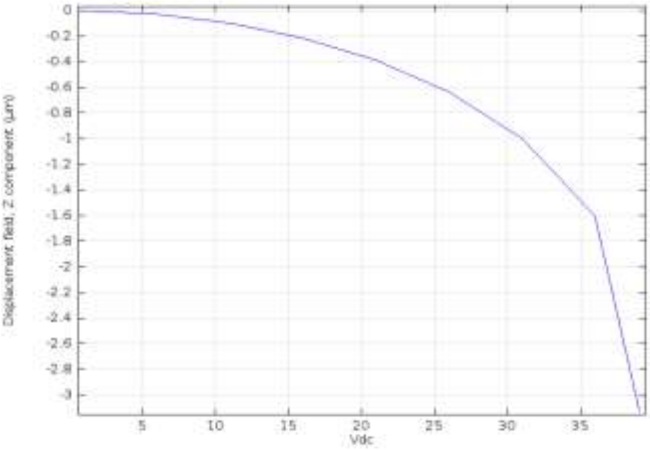

Figure 4. Graphene based Perforated Cantilever beam displacement for different bias voltage.

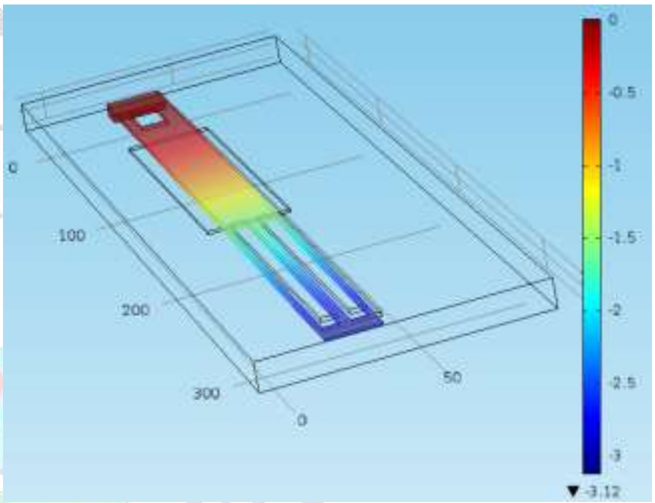

Figure 5. Graphene based Perforated Cantilever beam Tip Displacement in the Z-direction.

3.3 Silicon Carbide based Cantilever Beam

The Displacement of the Cantilever beam for different actuation voltage and Cantilever Tip displacement at 39.9125 volts for Silicon Carbide based cantilever beam is shown in Figure 6. and Figure 7. respectively.

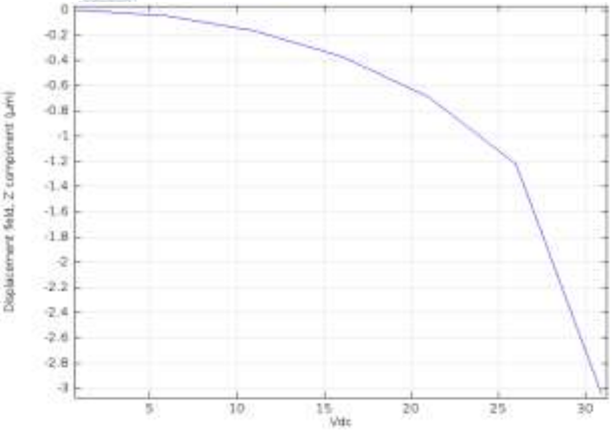

Figure 6. Silicon Carbide based Cantilever beam displacement for different bias voltage.

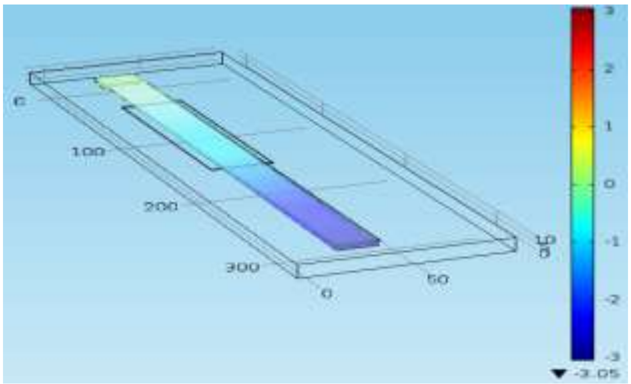

Figure 7. Silicon Carbide based Cantilever beam Tip Displacement in the Z-direction

Figure 6. shows that for applied voltage higher than 30.9125 volts, the Silicon Carbide based cantilever beam becomes unstable.

3.4 Silicon Carbide based Perforated Cantilever Beam

The Displacement of the perforated Cantilever beam for different actuation voltage and Cantilever Tip displacement at 26.225 volts for Silicon Carbide based perforated cantilever beam is shown in Figure 8. and Figure 9. Respectively.

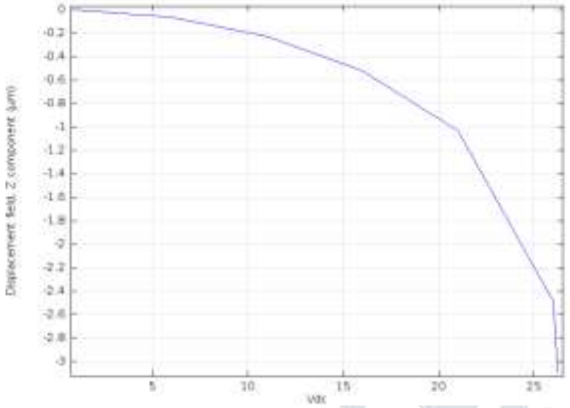

Figure 8. Silicon Carbide based Perforated Cantilever beam displacement for different bias voltage.

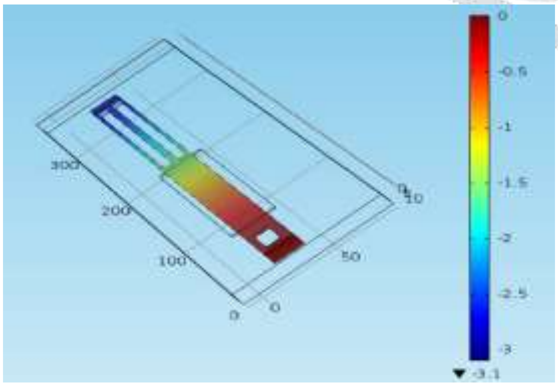

Figure 9. Silicon Carbide based Cantilever beam Tip Displacement in the Z-direction

Figure 8. shows that for applied voltage higher than 26.225 volts, the Silicon Carbide based cantilever beam becomes unstable.

4. DISCUSSION

With Perforations on the Cantilever beam, Pull-in Voltage could be reduced. The Comparison of Pull-in voltage of Cantilever based MEMS Switch using Silicon Carbide and Graphene Materials with and without Perforations is shown in Table 2.

Table 2. Pull-in Voltage Comparison with and without perforations.

Cantilever Beam	Pull-in Voltage in volts	
	Graphene based	***Silicon Carbide based***
Without Perforation	46.275	30.9125
With Perforation	39.0375	26.225

The Pull-in Voltage could also be reduced by reducing the thickness of the Cantilever beam. The Comparison of Pull-in voltage of Cantilever based MEMS Switch using Silicon Carbide and Graphene Materials with 1.5µm and 1µm thickness is shown in Table 3.

Table 3. Pull-in Voltage Comparison with different Beam thickness.

Cantilever Beam Thickness	Pull-in Voltage in volts	
	Graphene based	***Silicon Carbide based***
1.5µm	46.275	30.9125
1µm	24.35	16.225

The Electrostatic actuation of the Cantilever is similar to Parallel plate Capacitor. The distance between the plate decrease with increase in capacitance. As the actuation Voltage approaches, the capacitance increases.

5. CONCLUSION

The Simulation results shows the displacement of the Cantilever Beam for the applied Electrostatic Actuation Voltage. The Critical Actuation Voltage where the cantilever become unstable is the Pull-in Voltage. The Reliability of the MEMS Switch could be improved because of Silicon Carbide and Graphene material properties. This Switch could be used in Reconfigurable Antenna as Current Distribution changes with Switch ON and OFF positions.

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