ISSN 2347 - 3983
Volume 7, No. 11 November 2019
International Journal of Emerging Trends in Engineering Research
Available Online at http://www.warse.org/IJETER/static/pdf/file/ijeter267112019.pdf
https://doi.org/10.30534/ijeter/2019/267112019

Electromechanical and RF performance analysis of MEMS shunt configuration switch

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ABSTRACT

This paper presents a development and study of the capacitive shunt type RF MEMS switch. MEMS is a combination of mechanical and electromagnetic properties at the micro-level unit. The switch which can be used for switching purpose at RF and microwave frequencies is called RF MEMS switch. MEMS switch has many excellent advantages with potential characteristics and higher performances at radiofrequency. In this proposed design, a new type of capacitive switch is designed and analysed for RF electromagnetic properties in HFSS software and electromechanical properties in COMSOL multi-physics. The designed switch mainly consists of a substrate, co-planar waveguide (CPW), dielectric material and a metallic bridge.

Key words: Capacitive shunt**,** Electromagnetic. Electromechanical, Shunt type.

1.INTRODUCTION

A quick development in the field of communication has been occurred over the most recent couple of years. The future age requires gadgets with high transfer speed and low power utilization, one way is to replace the RF MEMS switches in the place of conventional switches in communication applications.

MEMS refers to Micro-Electro-Mechanical System with the arrangement of electromechanical and electromagnetic systems on a micro-meter scale **[1-8].** The combination of actuators, electronics, sensors and mechanical elements on a common substrate is a MEMS switch**[9,10]**. Among all the devices of MEMS, switches gain attention because of the advantages. Switches are two types, one is shunt and another one in series **[11,12].** MEMS is a robust and wide-spread applications in many industrial segments. **[13-15]**. MEMS switches exhibit better RF characteristics and less Direct Current power utilization but only with the two main features, such as the size and the cost. The manufacture procedures of MEMS gadgets and switches are similar to the circuits of silicon based **[16,17]**. Many shunt switches with parameters like insertion loss, return loss and actuation voltage are obtained in a good scale and have been reported in the literature **[7,8]**. An electromechanical and electromagnetic analysis is demonstrated, and we proposed a capacitive shunt asymmetric toggle switch. The yield reactions for the electromechanical framework are anticipated utilizing COMSOL multi-material science and the reactions for RF electromagnetic framework are done utilizing HFSS. The association of the paper is as per the following: the segment II clarifies the hypothetical examination and plan of the proposed switch. Area III proceeds with the outcomes and simulation results. At last, area IV finishes up the paper with conclusion.

2. THE DESIGNED SWITCH ALONG WITH ITS THEORETICAL ANALYSIS

The figure 1. Seen below is the diagrammatic representation of the newly designed RF MEMS switch. Silicon substrate thickness of 20 µm and Silicon dioxide with thickness of 15 µm which acts as a substrate and an oxide layer. Also a dielectric layer of thickness 0.1 µm. A metallic layer over the CPW signal line and both sides are connected to the anchors.

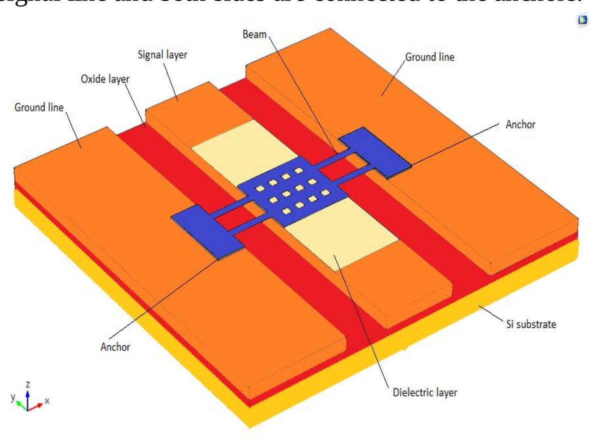

Figure 1: Diagrammatic representation of the proposed RF MEMS switch

Table 1: Measurements of the designed switch are shown below

Sl. no	Elements	Dimensions(μm)
1.	Thickness of substrate	20.0
2.	Thickness of dielectric	0.1
3.	Ground to signal line thickness	15.0
4.	Bridge length	300.0
5.	Bridge width	100.0
6.	Bridge thickness	1.0
7.	Oxide layer thickness	10.0
8.	Air gap	2.0

Various switch parameters are clarified underneath.

2.1.1 Spring constant

The spring constant K without any residual stress for shunt switch is calculated by **[3].**

$$K=32Ew\left(\frac{t}{l}\right)^3 \qquad (1)$$

With residual stress for a shunt switch is,

$$K= 32Ew\left(\frac{t}{l}\right)^3 + 8\sigma(1 - V)w\left(\frac{t}{l}\right)$$

The membrane is set at one end of the switch and has no residual pressure

Where σ= Biaxial residual stress (Pa),

V= Poison's ratio,

w= Width of the beam,

W= signal line width below the beam

2.1.2 Pull-in Voltage

Actuation voltage can be computed by using the below mentioned formula **[3]**.

$$V_p = \sqrt{\frac{8kg_0^{\ 3}}{27\varepsilon_0 Ww}} \qquad (2)$$

Here g_0 = Airgap

ε_0 = permittivity of the free space

2.1.3 Resonance frequency

A mechanical spring is given by [3]

$$\omega_0=\sqrt{\frac{K}{m}} \qquad (3)$$

2.1.4 Switching time

The time taken to change from On to Off state is toggling time and inversion of toggling time is its speed. The inversing time is given by **[3]**

$$Ts = \frac{3.67V_p}{V_s\omega_0} \qquad (4)$$

Where Up = pull-in Voltage,

V_s = switching voltage,

$V_s = (V_p)x(1.4)$

2.1.5 On-state Capacitance(Con)

Figure 2. shown below is the exhibition of switch by conducting power and a grouped model.

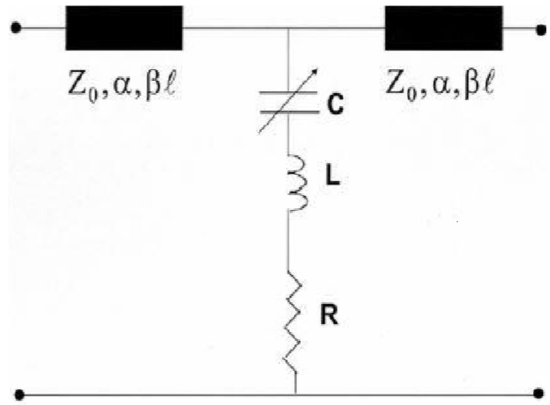

Figure 2: LCR circuit identical to RF MEMS switch.

C_{on} is computed by **[3]**

$$C_{on}=\frac{\varepsilon_0 Ww}{g+\frac{t_d}{\varepsilon_r}} \qquad (5)$$

Where, td=Thickness of the Dielectric layers.

The coefficient of reflection in upstate is given by **[3]**

$$S_{11} = \frac{-j\omega C_{on}Z_0}{2+j\omega C_{on}Z_0} \qquad (6)$$

The frequency of the resonance is calculated by

$$F_0 = \frac{1}{2\pi\sqrt{LC_{on}}} \qquad (7)$$

2.1.6 Down state capacitance (C_{off})

The down-state capability is computed from **[3]**

$$C_{off}=\frac{\varepsilon_0\varepsilon_r Ww}{t_d} \qquad (8)$$

2.1.7 Ratio of Off-state to On-state capacitances(R_{Ratio})

The proportion of the both off and on capacitances is given by **[3]**.

$$C_{ardio}=\frac{C_{off}}{C_{on}} \qquad (9)$$

Table 2: Theoretical values of RF MEMS Switch

Parameters	Obtained values
Spring Constant	9.6 N / m
Pull in voltage	16.03 volts
exchanging time	30.9 µs
Up-state Capacitance	43.9fF
Down-state Capacitance	6.99pF
Capacitance of down-state to up-state	159

3. RESULTS AND DISCUSSIONS

3.1 Analysis of the fixed-fixed beam switch in electro-mechanics

In exertion to contemplate the geometric parameters impact on the presentation of the designed switch, it's planned and recreated in COMSOL multi-physics. The geometric parameters are air-gap, dielectric materials, width of the beam and it's thickness. Every parameter is fluctuated each in turn.

3.1.1 Beam Width effect

Pull in voltage is inversely proportional to the width of the beam, so as beam width raises pull in voltage reduces, it is clearly seen in graphs below.

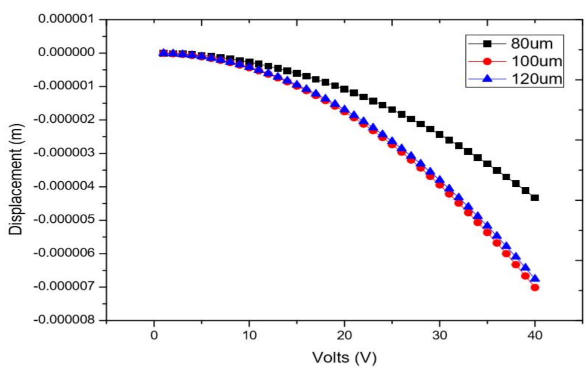

Figure 3: Displacement vs Voltage graphs for dissimilar beam width values

3.1.2 Impact of the air gap

Figure 4 exhibits the graphs for the displacement Vs volts with differing air gaps. Changes the air gap displacement is observed. So, as the air gap reduces, voltage also reduces. But in fabrication and manufacturing, less air gap is not preferable.

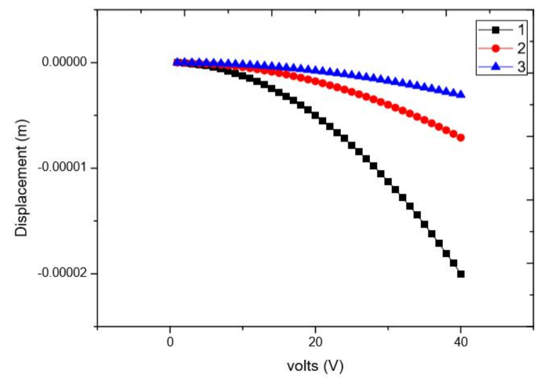

Figure 4: Graphs for different Air gaps (Displacement vs voltages)

3.1.3 Beam thickness effect

Figure 5. Shows the thickness of the beam effect on the pull in voltage. It's seen that with the reduced thickness of the beam, the pull-in voltage also reduces. Beam thickness of 0.5 µm has a lesser actuation voltage contrasted with 1 µm and 1.5 µm.

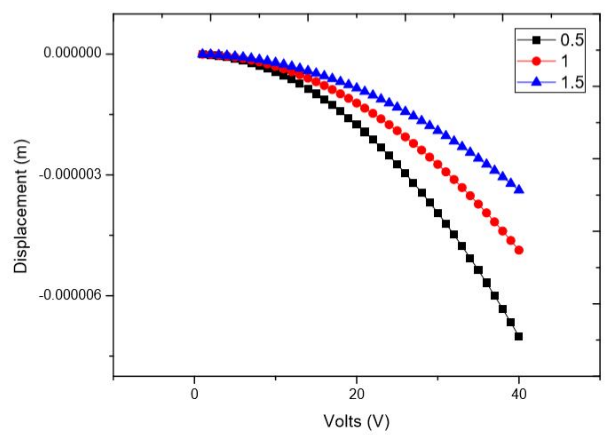

Figure 5: For different beam thickness values Displacement Vs Voltage graph.

3.1.4 Impact of the beam and the dielectric materials

To obtain the best performance, it is necessary to select the best output of the genuine conductor and dielectric material. Of all the conductors chosen, for gold it provides the best deflection at less voltage.

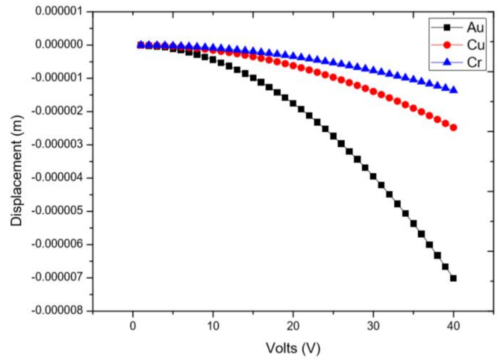

Figure 6: Displacement vs Voltage graph for various conducting materials

From all the dielectric materials, Si3N4 gives the good displacement for less voltage, can be seen in figure 7. The displacement obtained for remaining two materials are nearly same.

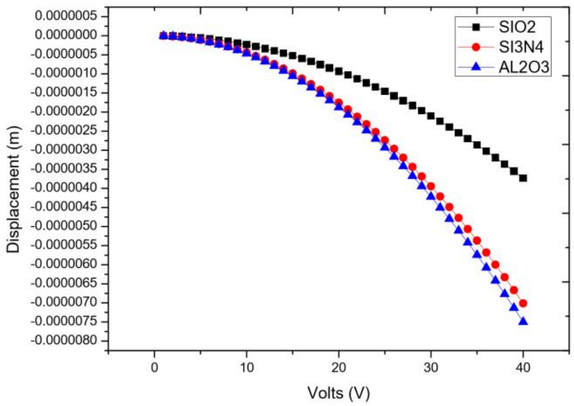

Figure 7: Graphs for different dielectric materials

3.1.5 Analysis of Switching time

Switching time is the function of w_0, V_{IP} and V_s of the switch considered from equation (4). Figure 8. Shown below is the plot of switching time vs source voltage. The switching time observed is 30.09 µs at pull-in voltage 16.02v.

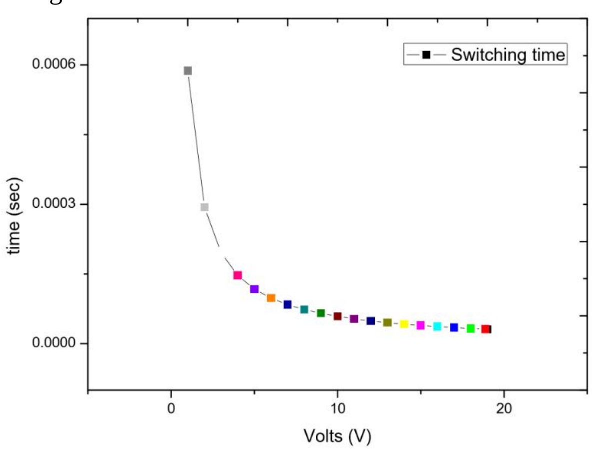

Figure 8: Switching time Vs voltage

3.1.6 Analysis of up-state and down-state capacitances

The measure of power ratio s a function of the difference in power of the both the states of switch. Up-state capacitance is the rely on the dielectric thickness, area of the beam and permittivity. Figure. 9 shows the capacitance for upstate of 43.9 fF and capacitance for downstate of 6.99 pF. So, the proportion of off-state to on-state capacitances obtained is 159.

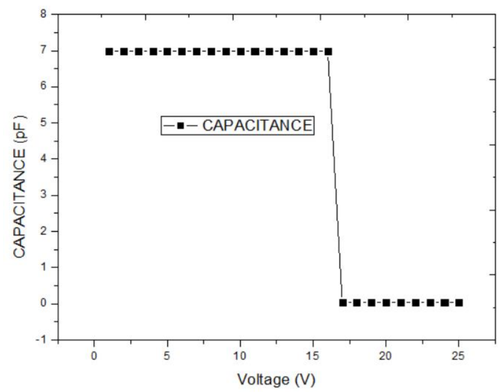

Figure 9: Switch capacitance vs voltage

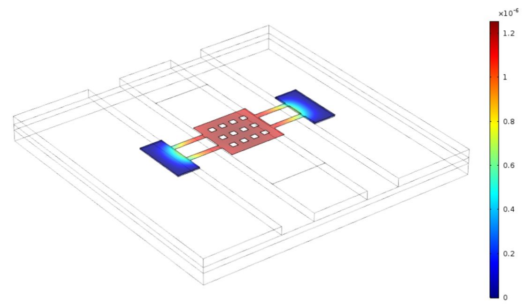

Figure. 10: Deflection of the beam

3.2 Electromagnetic Analysis of the RF MEMS switch

Evaluation of radio frequency is preformed using HFSS technology. Return and isolation of the insertion are critical parameters for the system to validate the switch output. The gap between the electrodes is 2µm and Si_3N_4 as dielectric material. The frequency range of 0-10Ghz was calculated.

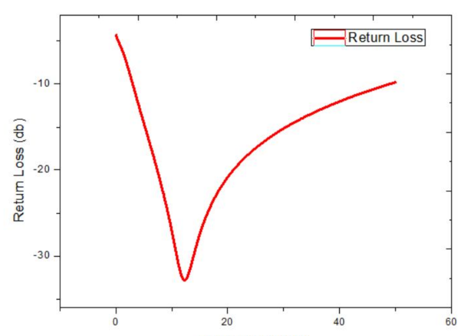

Figure 11: ON state Return-loss(S_{11})

The simulation for electromagnetic characteristics takes place at 0-10GHz and the parameters are evaluated. At On condition return loss is observed from the figure 11 in the range of -5 to -35 dB. And figure.12 shows the excellent insertion loss of -0.01 to -0.5 dB in On condition.

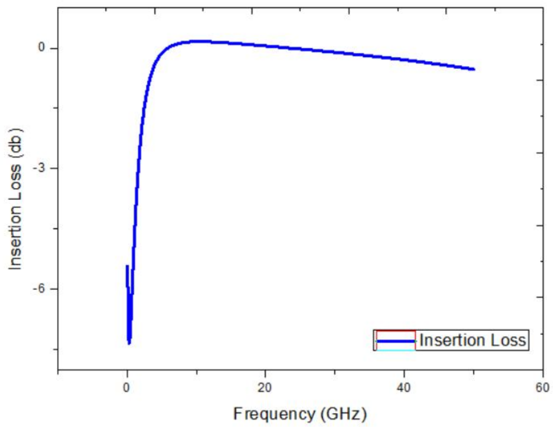

Figure 12: ON state Insertion-loss(S_{21})

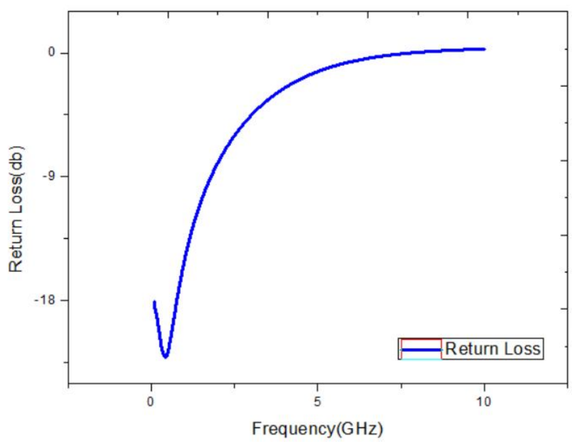

Figure 13: graphical representation of OFF state return loss(S_{11})

In Figure. 13 indicates the OFF state return loss within the range of -0.1 to -20 dB. Figure.14 shows the isolation loss within the range of -1 to -17 dB.

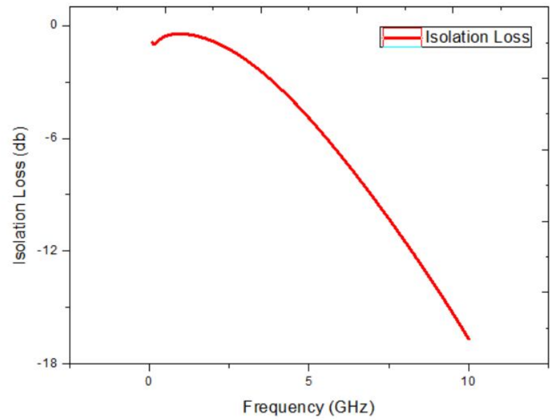

Figure14: graphical representation of Isolation loss(S_{21}) in OFF state.

4. CONCLUSION

In this paper, a fixed-fixed shunt type RF MEMS switch with electromechanics and electromagnetic properties is presented with different parameters. By observing the graphs, return and insertion losses at On state are observed as <-35db and >-0.1db at 10GHz. For the switch, isolation is higher than -15dB at 10GHz in OFF state. The switch has a reasonable capacitance ration of 159. The switch that has designed exhibited excellent RF characteristics and is extremely useful in tuneable filter applications.

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