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Design and Performance analysis of meanders-based RF MEMS shunt configuration switch

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ABSTRACT

In this paper, we have proposed a new type of RF MEMS Capacitive Shunt Asymmetric Toggle 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: Residual Stress, Pull in voltage.

1. INTRODUCTION

In the last few years, there has been a rapidgrowth in the field of communication. Future generation requires high bandwidth and low power consumption devices, one way is toreplace RF MEMS switches in communication applications instead of conventional switch [1-3]. MEMS refer to Micro-Electro-Mechanical System with the arrangement of electromechanical and electromagnetic systems in a micrometer scale [4]. The combination of actuators, electronics, sensors and mechanical elements on a common substrate is a MEMS switch. Among all the devices of MEMS, switches gain an attention because of the advantages [5]. Switches are two types; one is shunt and another one is series. MEMS is reliable and primary concern for the designers with its increasing applications in many industrial segments in the form of pressure sensors, inertial sensors and RF MEMS switches. MEMS switches exhibit high RF performance and low DC power consumption of electro-mechanical switches but only with the features of size and cost of semiconductor switches [6-7]. An electromechanical and electromagnetic analysis is demonstrated, and we proposed a capacitive shunt asymmetric toggle switch. The output responses for electromechanical system are predicted using COMSOL multi-physics and after the responses for RF electromagnetic system is analysed using HFSS.

2. DESIGNED SWITCH AND ITS THEORITICAL MEASUREMENTS

The fig below is our schematic switch. Silicon is the substrate which has thickness 20µm, dielectric layer has thickness 0.1µm. SiO2 oxide layer is of thickness 15µm which is on top of the substrate. A metallic beam is placed on its fixed anchors on the left and right ground lines.

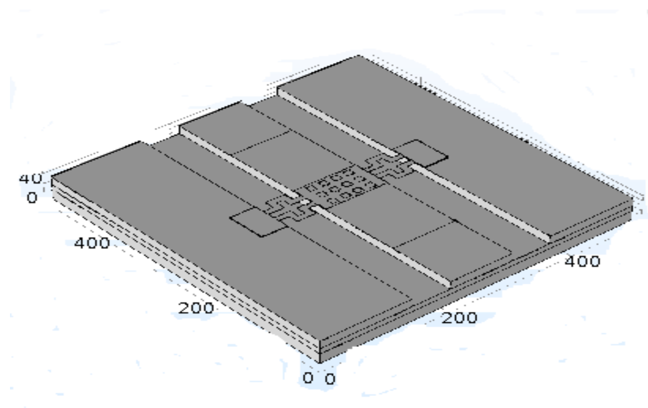

Figure 1: Proposed Switch Design

Table1: Proposed switch dimensions

S.NO	Material	Dimension (um)
1	Substrate thickness	20
2	Ground and signal line	15
3	Dielectric layer	0.1
4	Oxide layer	10
5	Bridge Length	300
6	Bridge Width	60
7	Bridge Thickness	0.5
8	Air gap	1

The parameters for the switch is explained below.

Spring constant

The spring constant K without residual stress for shunt switch is given by

$$K=32E\,w\left(\frac{t}{l}\right)^3$$

The spring constant K for proposed residual pressure beam is

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

For a series switch, it doesn't contain any residual stress because the layer is fixed on one side.

Where σ = residual stress (Pa),
w = width of beam,
W = signal line width.

Switching time

The required time to change from HIGH to LOW state is toggling time and inversion of toggling time is its speed. The inversing time is given by

$$Ts = \frac{3.67V_p}{V_s\omega_0}$$

Where Vp = pull-in voltage,
Vs =supply voltage,
Vs = 1.4Vp

Capacitance at ON state (Con)

Two sections of transmission line and lumped model is explained by shunt switch which was shown in below figure.

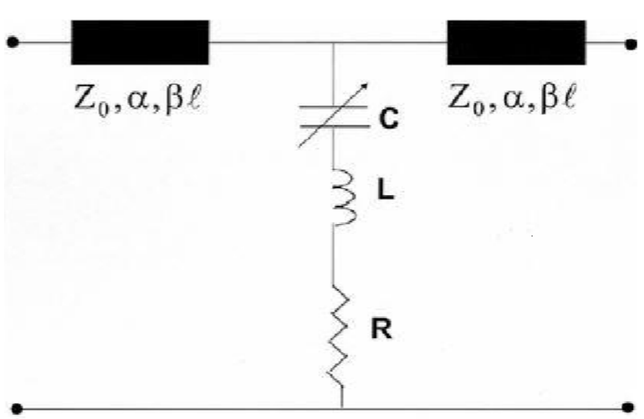

Figure 2: Equivalent LCR circuit for any switch.

The Capacitance C_{on} is measured by

$$C_{on} = \frac{\varepsilon_0 Ww}{g + \frac{t_d}{\varepsilon_r}}$$

Where td = Thickness of the oxide layer

The capacitance in upstate is $$C_{on} = \frac{\varepsilon_0 Ww}{g + \frac{t_d}{\varepsilon_r}}$$

Resonant frequency is calculated by:

$$F_0 = \frac{1}{2\pi\sqrt{LC_{on}}}$$

Capacitance at OFF state (C_{off})

Capacitance (Coff) is measured by

$$C_{off} = \frac{\varepsilon_0\varepsilon_r Ww}{t_d}$$

Capacitance Ratio (C_{ratio}) It is calculated by

$$C_{ratio} = \frac{C_{off}}{C_{on}}$$

Table 2: Theoretical values of the RF MEMS Switch

Switch parameter	Switch
Spring constant	14.72
Pull-in-voltage	9.06
Switching time	35ms
Up state capacitance	4.1976
Down state capacitance	4.19
Downstate to upstate capacitance	79.9

Table 3: Practical values of the RF MEMS Switch

Switch parameter	Switch
Spring constant	14.72
Pull-in-voltage	13.07V
Switching time	50.22ms
Upstate capacitance	4.1976
Downstate capacitance	4.19
Downstate to upstate capacitance	79.9

3. RESULTS AND DISCUSSIONS

Designed and simulated in COMSOL multiphysics in the stu dy of the effect of geometric parameters on the switch's performance analysis. The geometric parameters here are the width and thickness of the tube, air gap and the dielectric content each parameter varies from one to the next.

Effect of beam width

Since the pull in voltage is inversely proportional to the beam diameter, the pull in voltage decreases as the beam's size increases.

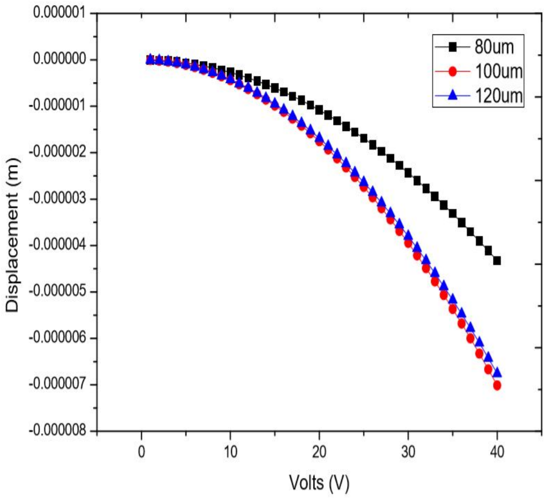

Figure 3: Graphs obtained for 80um, 100um and 120um beam width values

Air gap effects

By changing the air gap displacement is observed. Voltage reduced when air gap is small. Less air gap is not suitable for fabrication process.

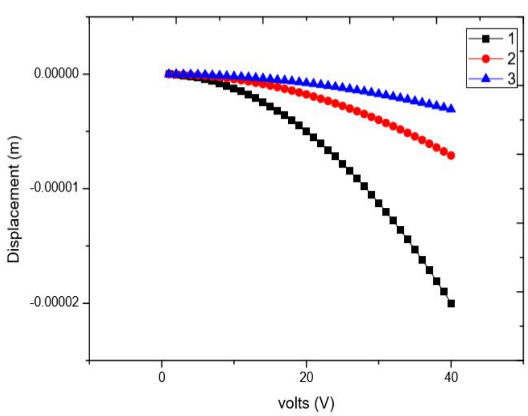

Figure 4: Graphs obtained for 1, 2 and 3 space air gap measurements

Effect of beam thickness

It is clearly seen that the voltage of the actuation also decreases with the decreased beam thickness. The 0.5um beam has the lower voltage actuation compared 1um and 1,5um.

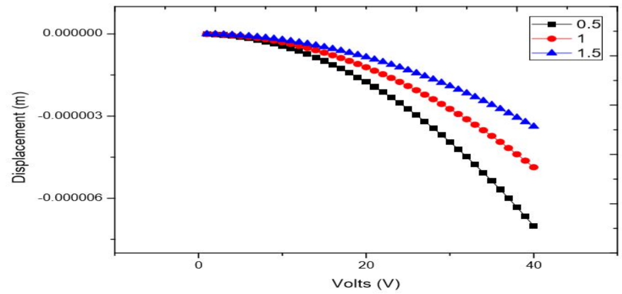

Figure 5: Graphs obtained for 0.5, 1 and 1.5 beam thickness values.

Beam effect and dielectric material effect

A suitable conductor and dielectric material should be chose n to achieve the best quality of a switch.Au gives the best dis placement for smaller voltage out of all three conductors.

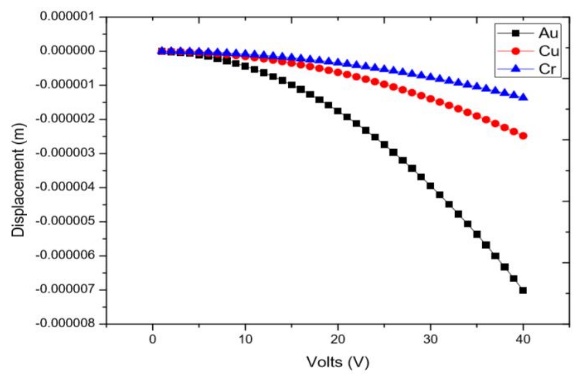

Figure 6: Plots obtained for Au, Cu and Cr materials.

From figure 7, the dielectric materials like Si3N4 in less voltage gives better displacement, as shown below. Other two displacement graphs are similar.

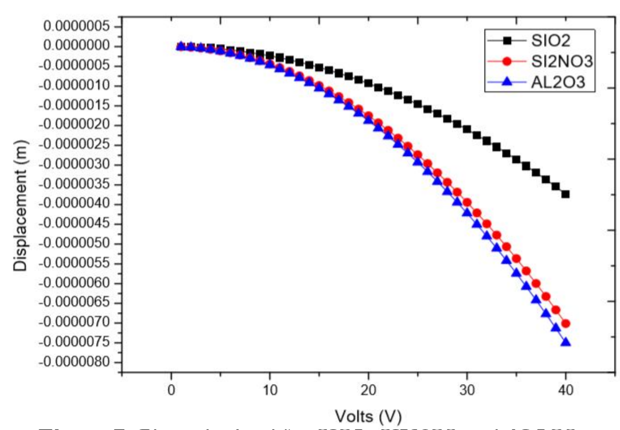

Figure 7: Plots obtained for SIO2, SI2NO3 and AL2O3 materials

Switching time (Ts) analysis

Ts is the relation of w_0,V_p and V_s of the switch taken from above solved formulae. The switching time observed is 50 µs at pull-in voltage 13.07.

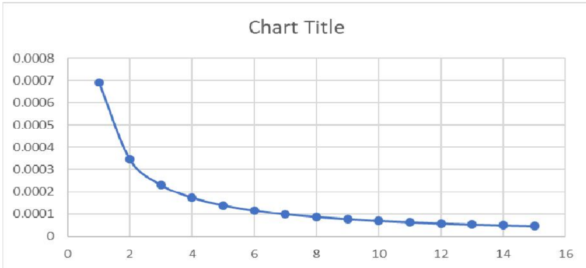

Figure 8: Switching time (Vs) Voltage

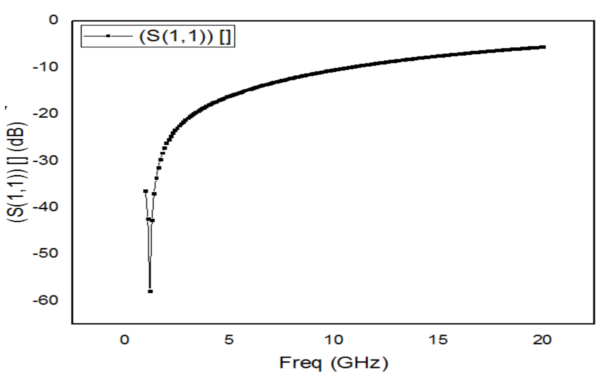

Figure 9: ON state Return loss (S_{11}).

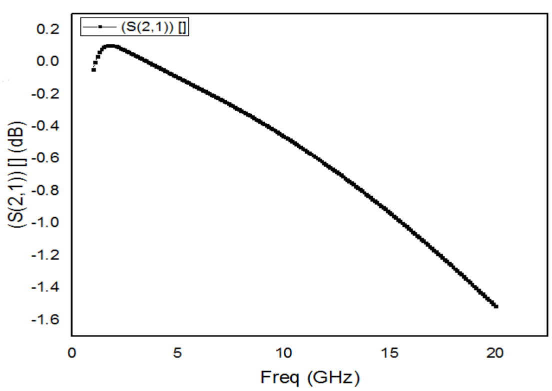

Figure 10: OFF state Insertion loss(S_{21}).

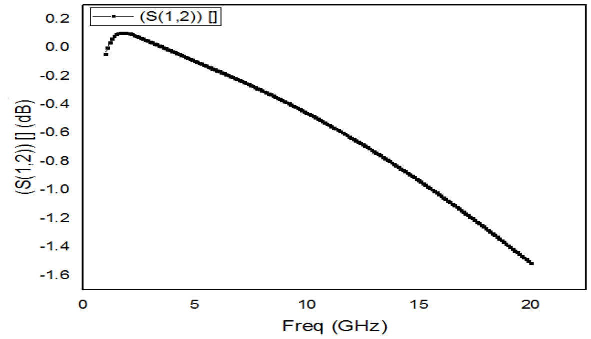

Figure 11: ON state Isolation loss(S_{12}).

4. CONCLUSION

In this paper, as a function of different parameters, a RF MEMS switch with study of electromechanical and electromagnetic properties is presented. Through analysing the charts, the loss of return is less than -35dB during ON state and the loss of insertion at 10GHz is less than -0.1dB. Isolation at 10GHz in OFF state is higher than -11dB for the switch. The switch that has been designed shows the excellent

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