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Design and Analysis of a Novel Low Actuated Voltage RF MEMS Shunt Capacitive Switch

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***Abstract*— This Paper presents design, analysis, proposed fabrication process and simulation of a novel low actuated voltage shunt capacitive RF MEMS Switch. The Air gap in between the membrane and CPW signal line is 1.5 µm. The lowest actuation voltage of switch is 3 Volts. The proposed fixed-fixed flexures beam structure provides excellent RF Characteristics (Isolation -43 dB at 28 GHZ and insertion loss -0.12 dB at 28 GHZ).**

***Index Terms*— Actuation voltage, Coplanar wave guide, Spring constant, scattering Parameters.**

I. INTRODUCTION

In the last decade huge amount of work have done on RF MEMS switches. Which are used as switching devices, working at radio frequencies. Since they exhibits number of advantages over PIN diodes or field effect transistor (FET) switches. For example- Low or near about zero power consumption, very high isolation, very low insertion loss and very good linearity [1,2 and 3]. This leads to it an ideal for wireless equipments working in ground and space for example- mobile cell phones, Base station and satellites. However RF MEMS Switches have some downsides for examples- relatively low switching speed, low power handling, High-voltage, low long term life, and packaging problems. Mainly a large electrostatic force produced at very high voltage 15-60 volts is required for RF MEMS Switches to have satisfactory operation. Since the actuation voltage or the pull in voltage (V_{PI}) of RF MEMS Switch is higher than the standard voltages of CMOS, Which is usually 5 Volts or less.
It results in that the RF MEMS switches are not compatible with the control circuits and others. Therefore it is impossible to integrate them in a single chip [4].
Therefore one most important job of RF MEMS Switch is to decrease actuation voltage V_{PI}.
The propose of this paper is to design and analyze RF MEMS switch to attain actuation voltage below 4 Volts. This is achieved by using fixed-fixed flexures beam structure.

A. Design of Switch

The pull in voltage (V_{PI}) is given by [5];

$$V_{PI} = \sqrt{\frac{8k_Z g_o^{\ 3}}{27A\varepsilon_o}} \qquad (1)$$

Where, k_Z is spring constant of membrane, g_o is gap between the movable membrane and CPW signal line and A is the actuation area.
Hence from equation (1) it clears that the pull in voltage V_{PI} can be reduced by three ways-

1. By reducing g_o which results in lower actuation voltage. But this way can be used at low frequency applications. Since it will unfavorably affect the high frequency OFF- State RF MEMS Switch performance by compromising the switch isolation (for series switch) or insertion loss (for shunt switch).
2. By reducing the actuation area. But this will not be useful solution since the compactness is prime issue and adaption of MEMS technology is to achieve miniaturization.
3. By reducing the value of spring constant K_Z. So fixed-fixed flexures beam structure is used which offers lower spring constant without increasing the size and weight of deceive.

Thus fixed-fixed flexures beam structure is important for low actuation voltage. The configuration of fixed-fixed flexures beam structure is shown in “Fig 1”. The spring constant k_Z for fixed-fixed flexures beam structure is given by [6],

$$k_Z = 4Ew\left(\frac{t}{l}\right)^3 \qquad (2)$$

Where, E is Young’s Modulus of membrane and t is thickness of membrane.

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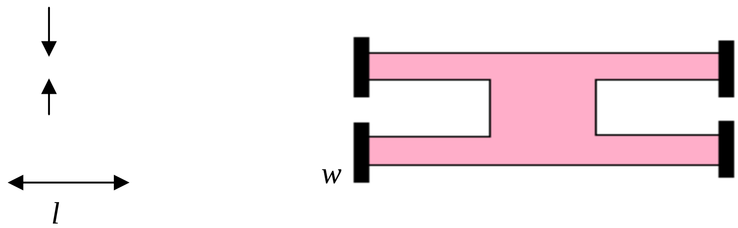


Fig. 1. Fixed-fixed flexures Beam Structure

I. FBRICATION PROCESS

The coplanar wave guide (CPW) structure preferred for RF MEMS Switch is S/W/S = 84/120/84 µm, H = 600 µm (50 ohm) above silicon substrate as shown in "Fig. 2".

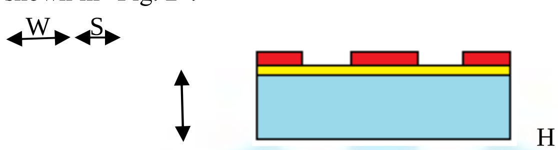
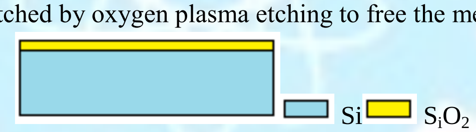


Fig. 2. CPW Structure for switch

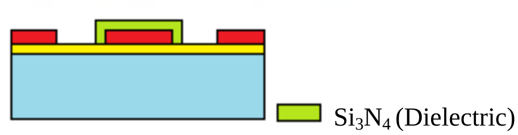
The switch is fabricated by using five masks fabrication Process.

1. A layer of 1 µm thick oxide is deposited on the silicon (Si) substrate as buffer layer as Shown in "Fig. 2(a)".
2. A layer of 4 µm of gold (Au) is sputtered and patterned for CPW transmission line as Shown in "Fig. 2(b)".
3. A 0.15µm thick plasma enhanced chemical vapor deposition (PECVD) Si_3N_4 is deposited and patterned as dielectric layer in between membrane and CPW signal line as Shown in "Fig. 2(c)".
4. A layer of photo resist with 4 µm thickness is spun coated and patterned to fill in the CPW slots (for obtaining flat membrane) as Shown in "Fig. 2(d)".
5. A 1.5 µm thick photo resist sacrificial layer is spun coated and patterned as Shown in "Fig. 2(e)".
6. A 0.6 µm thick layer of gold (Au) thin film is evaporated and wet etched to form bridge as Shown in "Fig. 2(f)".
7. All the sacrificial photo resist is etched by oxygen plasma etching to free the metal bridge as Shown in "Fig. 2(g)".

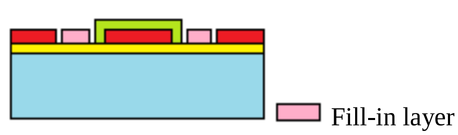


(a)

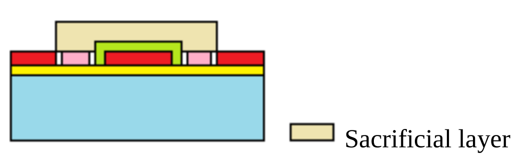
(b)



(c)



(d)



(e)

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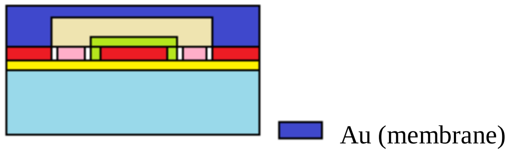
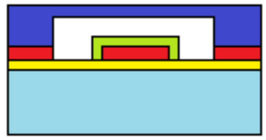


(f)



(g)

Fig. 3. Fabrication process flow.

The Detailed dimensions of switch are in Table I.

TABLE I
Detailed dimensions

g_o (µm)	A (µm)	w (µm)	l (µm)	t (µm)	L (µm)
1.5	120×40	10	184	0.6	508

II. SIMULATION RESULTS

A. Electrostatic Performance

Simulations are done by using Coventor Ware software and the 3D structure of RF MEMS Switch is shown in “Fig. 4” Displacement Vs. voltage plot shown in “Fig. 5”. This shows that the Pull-in voltage of proposed fixed-fixed flexures beam structure is 3 volts. Displacement of the membrane at the desired pull in voltage is shown in “Fig. 6”.

“Fig. 6” shows that at pull in voltage, the membrane and the pull in CPW signal line create a parallel plate capacitor with silicon nitride (Si_3N_4) as dielectric layer in between membrane and CPW signal line. This referred as down state capacitance (Cd). Since, in upstate of RF MEMS Switch the thickness of dielectric is insignificant as compare to air gap, so the up state capacitance is created by pull in membrane and CPW signal line with air as a dielectric layer. This capacitance is referred as up state capacitance (Cu).

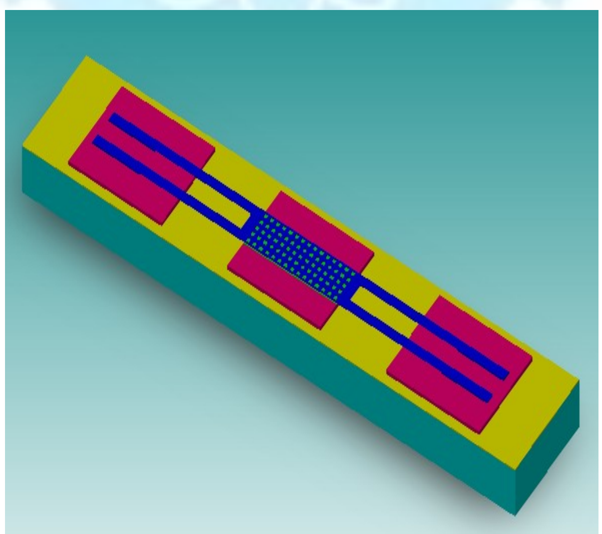


Fig. 4. Three dimensional model of RF MEMS Switch

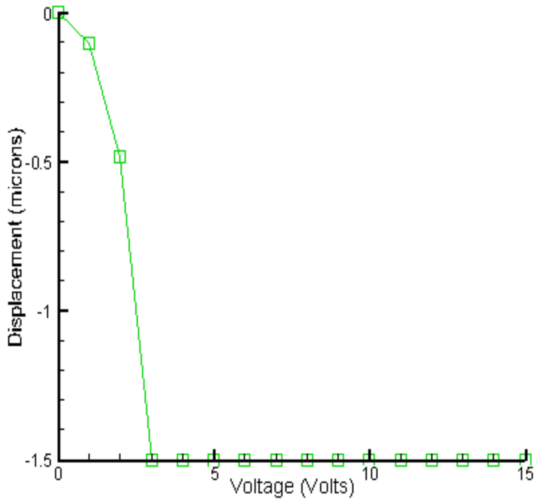


Fig. 5. Displacement Vs Voltage plot

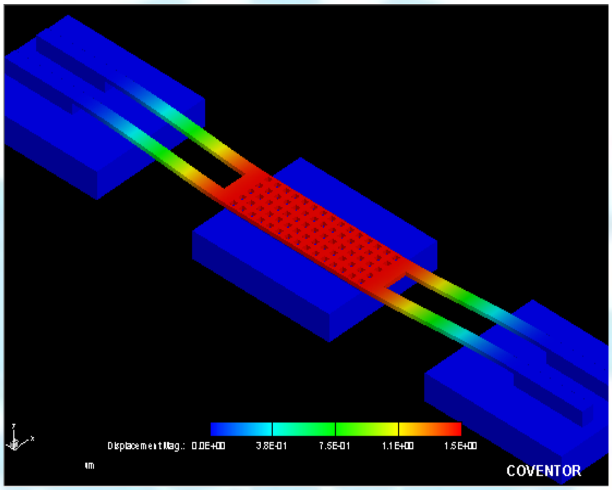


Fig. 6. Displacement Vs Voltage plot

B. RF Performance

As we know that S_{11} and S_{21} parameters of RF MEMS switch are only calculated by C_u and C_d respectively. The relationships in between S_{11} and C_u and in between S_{21} and C_d are expressed as follows [6]-

$$|S_{11}|^2 \approx \frac{\omega^2 C_u^2 Z_o^2}{4} \quad (3)$$

$$|S_{21}|^2 \approx \frac{4}{\omega^2 C_d^2 Z_o^2} \quad (4)$$

Simulation of insertion loss S_{12} and isolation S_{21} are done by HFSS Software and the plots for S_{12} and S_{21} are shown in "Fig. 7" and "Fig. 8" respectively.

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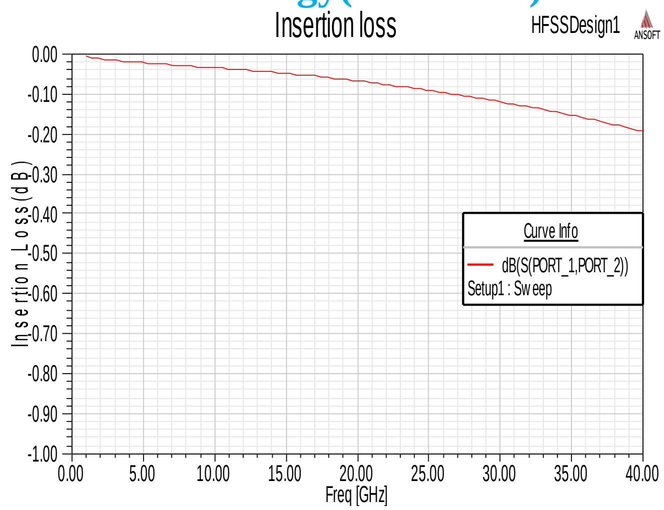

Fig. 7. Insertion Loss (UP State)

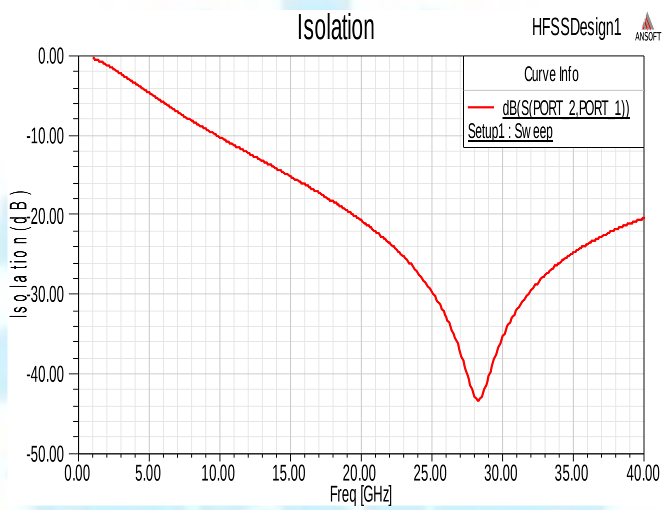

Fig. 8. Isolation Loss (Down State)

III. CONCLUSION

Simulated results shows that very low actuation voltage of RF MEMS switch by using fixed-fixed flexure beam structure is achieved i.e. 3 volts, shown in “Fig. 5”. Simulated results also shows excellent RF Characteristics i.e. very low insertion loss -0.12dB at 28 GHZ shown in Fig. 7 and very high Isolation -43dB at 28 GHZ shown in “Fig. 8”.

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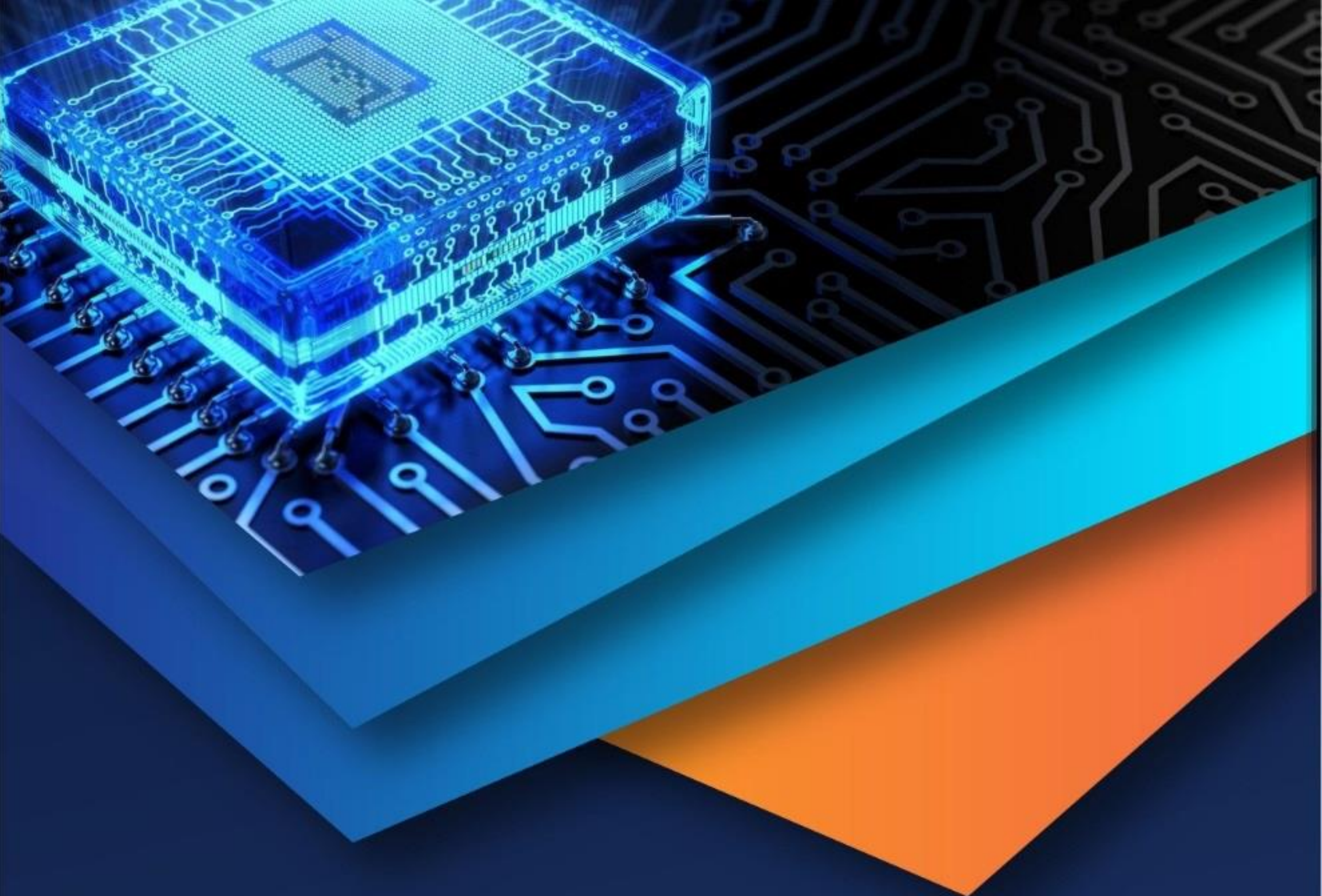

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