

Design and Analysis of a Low Actuated Voltage RF MEMS Shunt Capacitive Switch for Ka Band

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Abstract— RF MEMS Switches are one of the most prominent and remarkable future micro-machined products that have gain attention in last year's. This Paper presents design, analysis and proposed fabrication process and simulation of a 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 2 Volts. The proposed fixed-fixed flexures beam design provides excellent RF Characteristics (Isolation -44 dB at 26.5 GHZ and insertion loss -0.26 dB at 26.5 GHZ). The results show that the proposed switch is suitable for Ka- band applications.

Index Terms— Actuation voltage, Coplanar wave guide, Spring constant, scattering Parameters, down state capacitance.

I. INTRODUCTION

RF MEMS switches have been considered as a better substitute to the PIN diode and GaAs FET transistors. RF MEMS switches depicts better electrical performance characteristics, high isolation, very low insertion loss, low or approximately zero power consumption and outstanding linearity [2 and 3]. This makes it ideal for wireless devices operating in home, ground, mobile, space spheres such as handsets, base station and satellites. However RF MEMS switches have certain downsides. The most serious is long term reliability; the ability for the RF MEMS switches to operate millions or billions of cycle is a big concern and must be focused and resolved.

The pull in voltage (V_{PI}) or the actuation voltage of RF MEMS switches is higher than the standard voltage of CMOS that is 5V or less. It can be concluded that the RF MEMS switches are not attuned with control circuits and others, so impossible to integrate them in a single chip [5]. Therefore one of the crucial task of RF MEMS switches is to reduce V_{PI} . The objective of the paper is to design and analyze RF MEMS switch to achieve actuation voltage as low as 2V or less. This is achieved by using fixed-fixed flexures design.

II. DESIGN OF SWITCH

The pull in voltage (V_{PI}) is represented by [4];

$$V_{PI} = \sqrt{\frac{8k_z g_o^3}{27A\epsilon_o}} \quad (1)$$

Where, k_z is spring constant of membrane, A is the actuation area and g_o is air gap between the movable membrane and CPW signal line.

Hence from equation (1) it clears that the pull in voltage V_{PI} can be minimized by following 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 increasing 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 device.

Thus fixed-fixed flexures beam design is important for low actuation voltage. The configuration of fixed-fixed flexures beam design is shown in "Fig 1". The spring constant k_z for fixed-fixed flexures beam structure is given by [1],

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

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

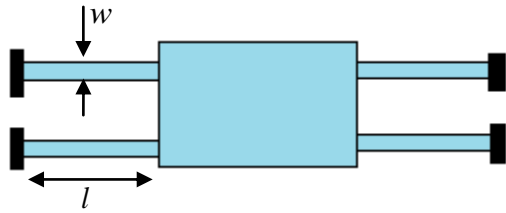


Fig. 1. Fixed-fixed flexures Beam Design

III. FABRICATION PROCESS

The coplanar wave guide (CPW) design proposed for RF MEMS Switch is $S/W/S = 84/120/84 \mu\text{m}$, $H = 600 \mu\text{m}$ (50 ohm) above silicon substrate as shown in “Fig. 2”.

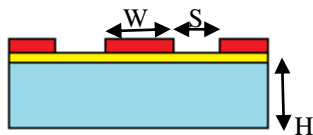


Fig. 2. CPW Design for switch

The switch is fabricated by five masks fabrication Process.

1. A layer of $1 \mu\text{m}$ thick oxide is deposited on the silicon (Si) substrate as buffer layer as Shown in “Fig. 2(a)”.
2. A layer of $4 \mu\text{m}$ of gold (Au) is sputtered and patterned for CPW transmission line as Shown in “Fig. 2(b)”.
3. A $0.15 \mu\text{m}$ 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 $4 \mu\text{m}$ thickness is spun coated and patterned to fill in the CPW slots (for obtaining flat membrane) as Shown in “Fig. 2(d)”.
5. A $1.5 \mu\text{m}$ thick photo resist sacrificial layer is spun coated and patterned as Shown in “Fig. 2(e)”.
6. A $0.6 \mu\text{m}$ 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)”.

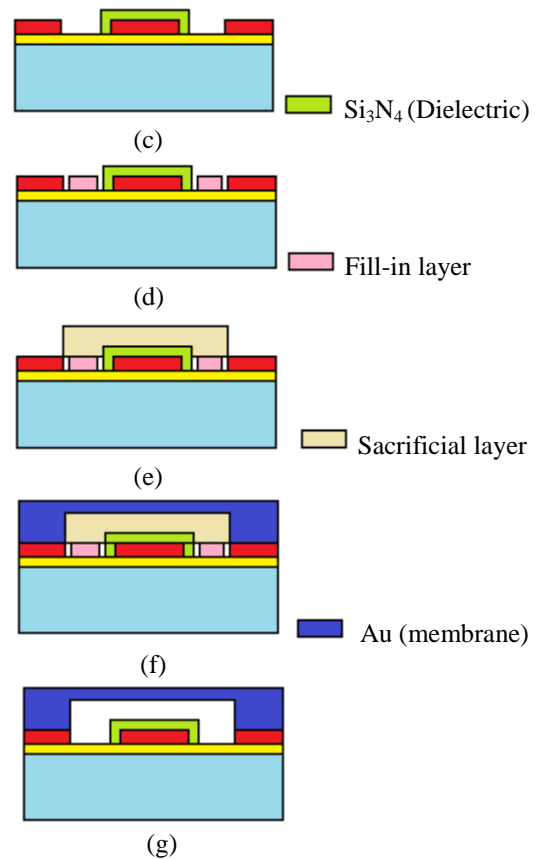
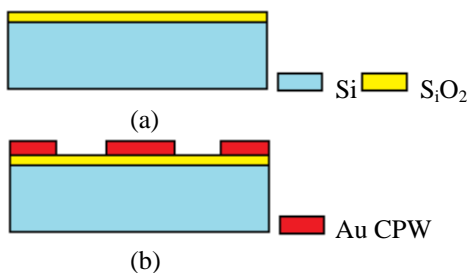


Fig. 3. Fabrication process flow.

The Detailed dimensions of switch are in Table I.

TABLE I.
Detailed dimensions

g_0 (μm)	A (μm)	W (μm)	l (μm)	t (μm)	L (μm)
1.5	120×60	10	194	0.6	528

IV. 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 2 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 (C_d). 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 (C_u). Capacitance vs. voltage plot in “Fig. 7” which shows that $C_d= 3\text{pF}$.

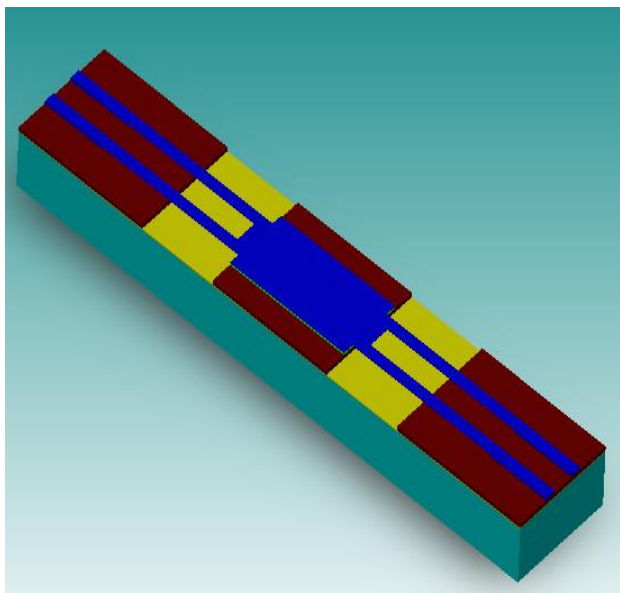


Fig. 4. Three dimensional model of RF MEMS Switch

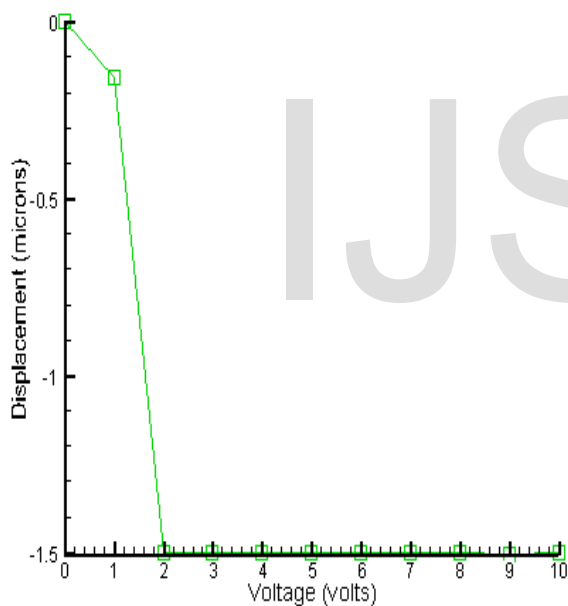


Fig. 5. Displacement Vs Voltage plot

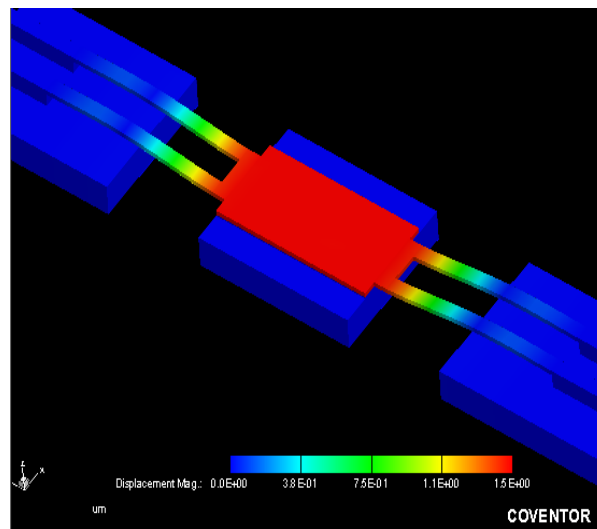


Fig. 6. Displacement Vs Voltage plot

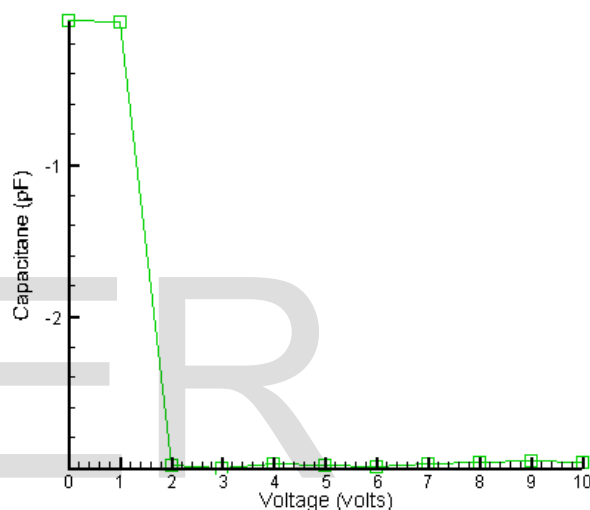


Fig. 7. Capacitance Vs Voltage plot

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 [1]-

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

$$|S_{21}|^2 \approx \frac{4}{\omega^2 C_d^2 Z_o^2} \tag{4}$$

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. 8” and “Fig. 9” respectively.

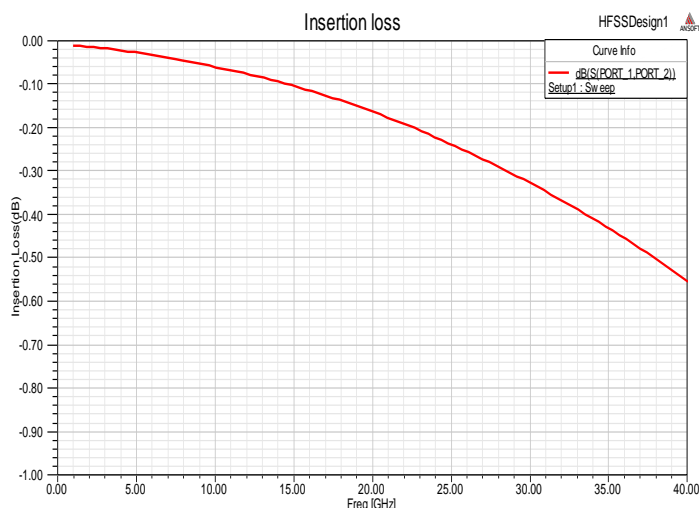


Fig. 8. Insertion Loss (UP State)

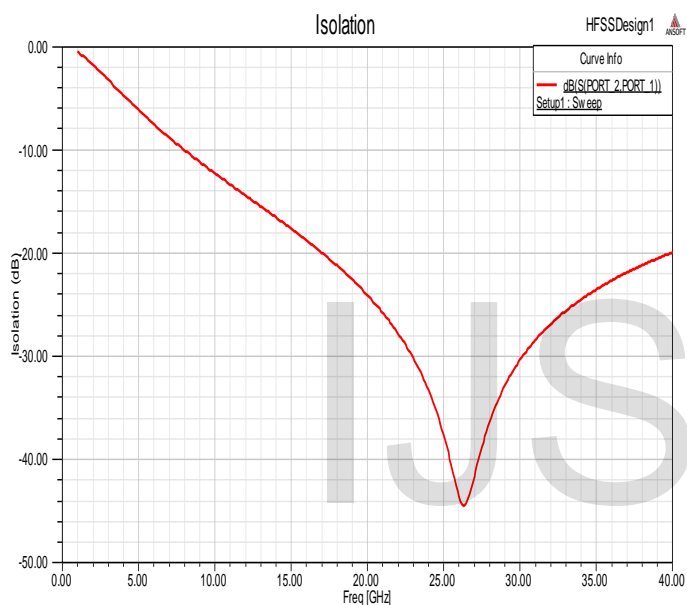


Fig. 9. Isolation Loss (Down State)

V. CONCLUSION

Simulated results shows that very low actuation voltage of RF MEMS switch by using fixed-fixed flexure beam design is achieved i.e. 2 volts, shown in “Fig. 5”. Simulated results also shows excellent RF Characteristics i.e. very low insertion loss -0.26dB at 26.5 GHZ shown in “Fig. 8” and very high Isolation -44dB at 26.5 GHZ shown in “Fig. 9”.

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