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Low loss STS based SPDT for X – Band applications

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Abstract

An approach to optimize the electromechanical parameters of RF MEMS SPDT designed for operation at 10 GHz, using high dielectric constant material (HfO_2) is presented and the results are compared to those for silicon dioxide – the conventional dielectric used for realizing capacitive shunt switches. The optimized length of CPW based transmission line ($\lambda/4$), computed by considering the permittivity of gold at microwave frequencies is approximately 2700 μm. The overall size of SPDT including the CPW ground area reduces from 12 mm^2 for SiO_2 dielectric layer based configuration to approximately 6 mm^2 for HfO_2 based capacitive SPDT. The reduction in dimensions ensures lower hysteresis in switch on-off characteristics and better stress related deformation control in electroplated metallic structures. The insertion loss, return loss and isolation are also better in the case of SPDT with HfO_2 compared to SiO_2 based devices. SPDT having SiO_2 dielectric layer shows insertion loss of 0.35 dB, return loss of 26.4 dB and isolation of 45.1 dB at 10 GHz, whereas SPDT having HfO_2 dielectric layer shows insertion loss of 0.08 dB, return loss of 35.7 dB and isolation of 48.8 dB at 10 GHz. Comparison of single switch response with different dielectrics is also presented.

"Keywords: Symmetric Toggle Switch; Hafnium Oxide; SPDT; dielctric constant"

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1. Introduction

RF MEMS switches have attracted lots of attention in the recent years mainly due to highly linear characteristics of the switches over a wide range of frequencies. The MEMS devices also offer better isolation (>30 dB) and low insertion loss (<0.15 dB) compared to contemporary solid state devices. With high levels of integration, negligible current, low power consumption and improved overall performance, RF switches are preferred for space, air borne and hand held communication applications [1]. MEMS switches closely resemble the electro-mechanical relays except the dimensional scale, superior performance and negligible power consumption. RF MEMS switching technology addresses many limitations of the conventional switch technology. In addition, they are inherently small and can be fabricated on different types of substrates using inexpensive batch-processing methods.

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SPDT switching circuits are widely employed in microwave and millimeter wave communication systems including signal routing in ‘transmit and receive’ applications, switched-line phase shifters, and wide-band tuning networks. Traditional integration of GaAs MESFETs and PIN diodes in the SPDT switching circuit [3, 4] is less favorable as it suffers from high insertion loss and low isolation at high frequencies over the GHz range. MEMS SPDT switching circuit involves two capacitive shunt MEMS switches placed a quarter wavelength from the center of the T-junction. When one of the switches is actuated, the virtual RF short is transformed to an open at the T-junction thus blocking nearly all the signal from passing to that port.

In this paper designing of SPDT has been discussed using Symmetric Toggle Switch (STS) [5]. STS is a capacitive type switch, which is based on push – pull mechanism to obviate the problem of self-biasing and external vibrations. As shown in Fig. 1 the device consists of a pair of micro-torsion actuators placed symmetrically around the transmission line.

2. Device Topology and Working Principle of Symmetric Toggle Switch

Symmetric Toggle Switch (STS) has been used to design SPDT, and an advantage of using high-k dielectric material has been discussed. The impact of change in dielectric material from SiO_2 having dielectric constant 3.9 to HfO_2 having dielectric constant 20, leads to the compactness in overall size of device with better electrical response. Designing of SPDT by using HfO_2 as a dielectric layer leads to almost 50% dimensional optimization. Fig. 1(a) and (b) shows the 3-D view and working principle of STS. STS is a capacitive switch based on 50Ω CPW configuration with torsion springs of movable membrane anchored to the ground planes of CPW. The bridge structure consists of two micro-torsion actuators, which are connected to each other through levers and an over-lap area. The membrane is at a gap of 3 μm from central conductor. The pairs of inner and outer actuation electrodes of two micro torsion actuators are electrically shorted together by polysilicon lines and are called "pull-in" and "pull-out" electrodes respectively. As shown in Fig. 1(b) when no bias voltage is applied, bridge is at a height of 3 μm from transmission line. Bias voltage applied at the inner electrodes, forces the bridge to make a contact with transmission line dielectric and switch provides isolation (off-state of STS), whereas when bias voltage is applied at the outer electrodes, bridge clamps to a height which is double the zero bias height of the bridge, giving low insertion loss (on-state of STS). Eq. 1 describes the pull-in voltage in terms of geometrical dimensions of movable bridge.

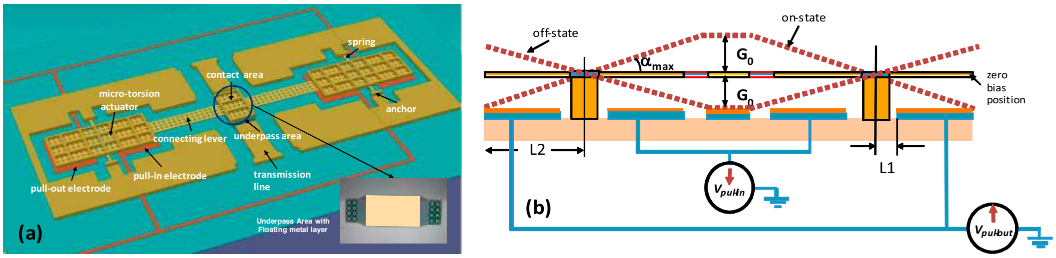

Fig 1(a): 3-D view and, (b): Working Principle of Symmetric Toggle Switch.

$$V_{Pull-in} = \sqrt{\frac{E}{2.3914\varepsilon_0 W}\left(\frac{g_0}{L}\right)^2\left[\frac{0.33}{(1-\nu)}\frac{h_t b_t^2}{l_t} + \frac{L}{l^2}\frac{bh^2}{6}\right]} \quad \text{..............................(1)}$$

where, L and W are length and width of actuation electrodes, g_0 is the gap, E is the Young's modulus of movable membrane material and l, b, h, l_t, b_t, h_t are lever and spring dimensions respectively [5,6].

The transmission coefficient (S21) for a shunt switch when modelled as limped capacitance is given by [7]

$$|S_{21}|^2 = 1/[1+\{\omega C Z_0/2\}^2] \quad \text{..(2)}$$

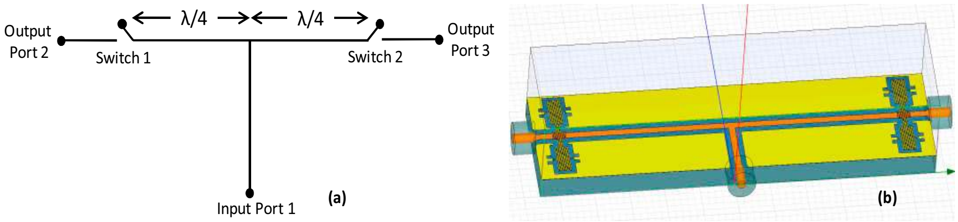

Fig 2 (a): Layout of SPDT, (b) Simulated 3-D view of SPDT, designed for X-Band, having best performance at 10 GHz.

Wher,e Z_0 represents the characteristic impedance of the line, C the capacitance of the switch and $\omega = 2\pi f$, the radian frequency. Insertion loss and the isolation are given by $-S_{21}$[dB] in on and off states respectively and are one of the prime measures for performance of a device. In switching from on to off state the frequency changes abruptly from insertion loss mode to isolation mode or vice versa. The operating range of the device is thus characterized by the ratio of frequencies in two states expressed as:

$$\frac{f_{insertion\,loss}}{f_{isolation}} = \frac{C_{down}}{C_{up}} = \frac{\varepsilon_d \, g_{air}}{t_d} \text{..........................}(3)$$

Where, t_d is the dielectric layer thickness, g_{air}= gap between the beam and bottom dielectric layer, ε_d = dielectric constant of the layer. Most of the devices designed with SiO_2 dielectric layers have the capacitance ratio around 100-120. For higher isolation (> 40dB) and lower insertion loss (< 0.1dB) capacitance ratios in range of 400-600 are required. Among the three process parameters in equation [5], the air gap and dielectric thickness are limited by the pull-in voltage range and break down voltage of the dielectric respectively. Thus it is imperative to use high dielectric constant material such as HfO_2 (19-27), tantalum oxide (21-28) or strontium titanate oxide (180-300) to have higher capacitance ratio. Hafnium oxide (HfO_2) being developed as next generation MOS gate oxide (19 - 25) has excellent process compatibility with concurrent IC technology. Dielectric strength higher than 10MV/cm, implies possible use of thinner layers to achieve better isolation. It also shows better resistance to dielectric charging, a major concern in capacitive MEMS switches. Pinhole-free HfO_2 films with thickness less than 100 nm can be deposited and pattered easily.

3. SPDT Design & Optimization

SPDT, as shown in Fig.2 has been designed for 10 GHz using two switches. For transmission line length calculations (λ/4), permittivity of gold at microwave frequencies has been considered, which gives a quarter wavelength of approximately 2700 μm. Incorporation of HfO_2 in individual switches and optimization of physical dimensions over the desired frequency range leads to almost 50% reduction in dimensions compared to structures

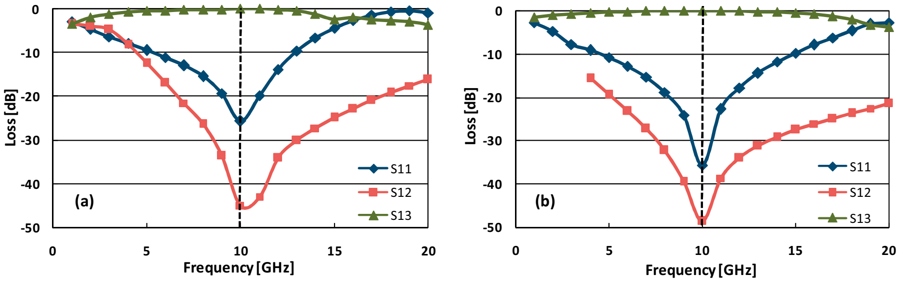

Figure 3: (a) Electrical performance of SPDT (SiO_2 dielectric layer) and switch1 in on-state and switch 2 in off-state. (b) Electrical performance of SPDT (HfO_2), with switch 1 in on-state and switch 2 in off-state. Insertion loss, return loss and isolation are better in the case of SPDT (HfO_2) compared to SPDT with SiO_2 as a dielectric layer.

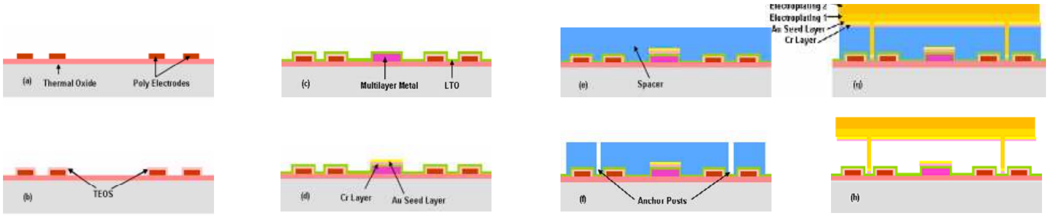

Fig. 4 (a) - (h): Schematic view of fabrication steps for RF Switch.

with SiO_2. Thin higher dielectric constant layers ensure increased capacitance of the switch, improving C_{down}/C_{up} ratio, which in turn improves the isolation and insertion loss. Fig. 3 (a) & 3 (b) show the comparison of SPDT with SiO_2 and HfO_2 as a dielectric layers. The device size in case of SiO_2 dielectric layer is approximately 12 mm^2 whereas in the case of HfO_2 it is approximately 6 mm^2. Also Fig. 3 (b) shows that the insertion loss, return loss and isolation are better in the case of SPDT with HfO_2 as compared to the SPDT with SiO_2 dielectric layer. SiO_2 based SPDT shows insertion loss of 0.35 dB, return loss of 26.4 and isolation of 45.1 dB at 10 GHz, whereas HfO_2 SPDT has insertion loss of 0.08 dB, return loss of 35.7 and isolation of 48.8 dB at 10 GHz.

4. Process Flow

Fig. 4 shows the schematic view of fabrication steps for RF switch [5]. High resistivity silicon wafers are used for the fabrication of RF MEMS switches. Initial thermal oxidation is followed by the LPCVD growth of polysilicon which is further doped to required resistivity and patterned to obtain actuation electrodes. Low temperature TEOS is deposited and patterned to open contact holes and prevents the short between actuation electrodes and movable membrane. The underpass area for signal transmission is a multilayer stack composed of sputtered Ti/TiN/Al:Si/Ti/TiN thin layers. After this SiO_2/HfO_2 layer is deposited by sputtering on the above stack and via holes are patterned through it. This oxide layer will act as a dielectric layer for the capacitive type switch and prevents the short circuit conditions between the underpass area and movable bridge. A floating metal layer can be deposited to obtain optimum capacitance and eliminating the deposition of refractory metals (in this case TiN) to obtain smooth contact layers. Movable structure is realized through two electroplating steps over a 3μm thick photoresist, used as a sacrificial layer. A seed layer of Cr/Au for electroplating is deposited by sputtering. This is followed by first gold electroplating step providing 1.5μm thick movable bridge. The second electroplating selectively increases the thickness to 5.0 μm for certain parts including CPW. After the removal of Au and Cr seed layers, switches are released by modified plasma ashing process to avoid stiction problem.

Acknowledgements

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References

[1] Gabriel M. Rebeiz, “RF MEMS Theory, Design and Technology”, 1st ed. *Wiley-Interscience*, 2003.
[2] C.L. Goldsmith, Y. Zhimin S. Eshelman, and D. Denniston, Performance of low-loss RF MEMS capacitive switches, IEEE Microwave Guided Wave Lett 8 (1998), 269–271.
[3] K. Kawakyu, Y. Ikeda, M. Nagaoka, K. Ishida, A. Kameyama, T. Nitta, M. Yoshimura, Y. Kitaura, N. Uchitomi, A novel resonant type GaAs SPDT switch IC with low distortion characteristics for 1.9 GHz personal handy-phone system, in: Proceedings of the IEEE MTT-S International Microwave Symp. Dig., 1996, pp. 647– 650.
[4] T. Shigematsu, N. Suematsu, N. Takeuchi, Y. Iyama, A. Mizobuchi, A 6–18 GHz 20W SPDT switch using shunt discrete PIN diodes, in: Proceedings of the IEEE MTT-S Int. Microwave Symp. Dig., 1997, pp. 527–530.
[5] K. Rangra, B. Margesin, L. Lorenzelli, F. Giacomozzi, C. Collini, Mario Zen, G. Soncini, L Del Tin, R Gaddi, “Symmetric Toggle Switch- a new type of RF MEMS Switch for Telecommunication Applications: Design and fabrication”, *Sensors and Actuators A*, vol. 123-124, pp. 505-514, September 2005.
[6] K. Maninder, Akshdeep Sharma, K. J. Rangra, Dinesh Kumar, Surinder Singh, “Design of compact, high capacitance ratio MEMS switches for X - Band applications using high-*k* dielectric materials*”, Microtech 2010,* 21-25 June, Anaheim, CA.
[7] H.A.C. Tilmanns, MEMS components for wireless communications in: Eurosensors XVI, *16th European Conference on Solid State Transducers*, Prague, Czech Republic, pp.1-34, September 15-18, 2002.