Sensors & Transducers, Vol. 186, Issue 3, March 2015, pp. 134-139

www.sensorsportal.com

Sensors & Transducers

http://www.sensorsportal.com

Low Loss High Isolation NEMS/MEMS Switch for High Frequency RF Applications

Elangovan R. and Usha Kiran Kommuri
School of Electronics Engineering, Vellore Institute of Technology, Chennai, TamilNadu, India
E-mail: elangovandevaki@gmail.com, usha.kiran@vit.ac.in

Received: 16 February 2015 /Accepted: 16 March 2015 /Published: 31 March 2015

Abstract: MEMS switches are advantageous in terms of low power consumption, switching times, high isolation, low insertion loss and many more. This paper proposes a MEMS switch with high isolation and low insertion loss. The model used is a CPW configuration with a cantilever series switch built on a silicon substrate. The switch parameters are optimized for the lowest insertion loss and return loss. An insertion loss values of -0.1305 dB in the down state with return loss of -38 dB and -75 dB of isolation have been observed in the high frequency range. *Copyright © 2015 IFSA Publishing, S. L.*

Keywords: NEMS, MEMS switch, Low Loss, High Isolation, RADAR.

1. Introduction

Nano-Electro-Mechanical Systems (NEMS) is the future of electronics. Two different electrostatic actuation models exist namely the capacitive switch and the metal-metal contact switch. High isolation in the switch OFF position and low insertion- loss in the ON position is expected. The cut-off frequencies obtained may reach a value of 40 THz [1]. The actuation voltage is the main feature of the switch.

Micro-Electro-Mechanical Systems (MEMS) technology has grown rapidly and entered into many communication and defense applications. At present, as the development in MEMS technology, Radio Frequency (RF) MEMS is one of the fastest growing areas in commercial MEMS technology. As a novel switch, RF MEMS switches have a myriad application in radar system and wireless communications. Comparing to semiconductor switches widely used in millimeter wave integrated circuits and microwave circuits, the novel device has a low insertion loss, good isolation, low return loss, high frequency, good Q-factor, high tuning ration, low cost and power consumption.

The components and subsystems used in radar are based on RF MEMS switches, switched capacitors, and varactors. Limiters protect active microwave circuitry from damaging power levels. Anti-stiction treatments involve the application of a molecular film to the micro-machine surface. [2]

2. Radar Applications

Radio Frequency Nano-Electro-Mechanical Systems have been proposed to replace the already existing components like the Active Electronically Steerable Antennas, Passive Electronically Scanned Arrays, phase shifters, radomes [3]. A wide bandwidth can be obtained by using RF NEMS switch as phase shifters in RADAR [4-12]. Although many switches are proposed but detailed study of NEMS switch is not available in the literature.

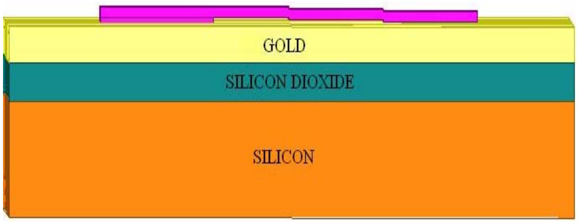
This paper presents the detailed optimization of parameters of NEMS switch for the RF characteristics.

 http://www.sensorsportal.com/HTML/DIGEST/P_2635.htm

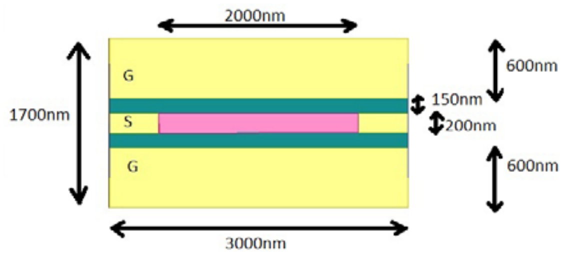
3. Design

3.1. Conventional NEMS Switch

The proposed NEMS switch is a cantilever beam developed on a 50 Ω Co-planar Wave-guide (CPW) with G/S/G = 150/200/150 nm as shown in Fig. 1. The substrate used is a silicon substrate of thickness 450 nm. The whole switch is fabricated on the silicon substrate with a silicon oxide layer on top of it [6]. A layer of SiO2 of about 150 nm is layered for the isolation purpose. The anchor for the beam is made of Gold of Young's Modulus 78 GPa, Poisson's ratio 0.44 and density 19280 Kgm^{-3}. A dielectric layer made of Silicon Nitride (SiN) is layered between the cantilever and CPW to avoid stiction in the down state.



(a) Side View



(b) Top View

Fig. 1. Structural representation of the switch.

3.2. Structural Variations

Various structures in the NEMS switch are altered to observe certain changes in the S-parameter Characteristics viz. Insertion loss and the return loss. As the down state is the important phase of a switch the isolation is ignored and is assumed to be constant. Although the dimensions of various structures are being changes it is taken care that the cantilever of the switch dimensions remains unaltered.

3.2.1. Substrate Height Change

Substrate of the switch is varied from 250 nm to 1000 nm. As we are aware that as the substrate dimensions changes the CPW G/S/G changes hence altering the substrate and G/S/G to maintain 50 Ω impedance [7] various combinations have been considered and tabulated.

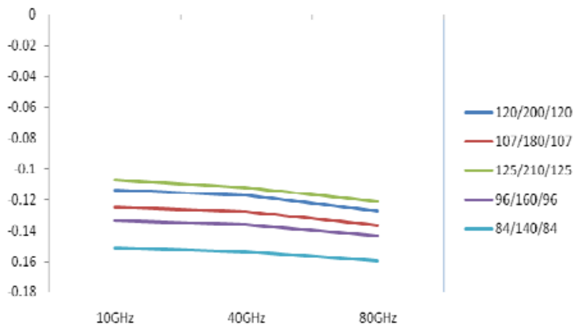
Table 1. Substrate height variations.

G/S/G	Height	Insertion LosS		
		10 GHz	**40 GHz**	**80 GHz**
110/250/110	250 nm	-0.094	-0.0987	-0.1105
100/150/100	470 nm	-0.1474	-0.1496	-0.1545
180/250/180	650 nm	-0.0883	-0.0911	-0.0989
80/130/80	800 nm	-0.1684	-0.17	-0.1738
125/200/125	1000 nm	-0.1091	-0.111	-0.1164
G/S/G	**Height**	**Return Loss**		
		10 GHz	**40 GHz**	**80 GHz**
110/250/110	250 nm	-30.2817	-29.7617	-28.9383
100/150/100	470 nm	-27.9256	-27.734	-27.6013
180/250/180	650 nm	-34.0348	-33.0942	-3.4035
80/130/80	800 nm	-27.2323	-27.0357	-26.7489
125/200/125	1000 nm	-37.4543	-38.2672	-37.0692

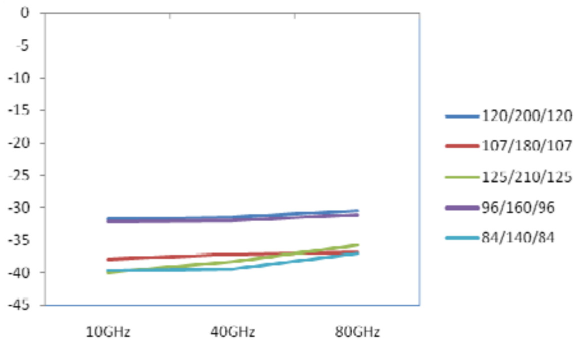
It is observed from the above table that 1000 nm with G/S/G of 125/200/125 is the optimized value for the substrate variations. These values are considered keeping in mind that the overall impedance of the circuit is 50 Ω. Although the G/S/G is determined, changing the CPW gap may alter the impedance hence keeping the impedance of 50 ohm in mind the gap is altered accordingly.

3.2.2. Variation in CPW G/S/G

After varying the substrate thickness, CPW G/S/G is varied accordingly. CPW G/S/G variations are shown in Fig. 2.



(a) Insertion Loss



(b) Return Loss

Fig. 2. CPW G/S/G variations: (a) Insertion loss, (b) Return loss of a RF NEMS Switch.

From the graph it is evident that the values of the insertion loss and return loss are better for 125/210/125. Hence 125/210/125 is taken as the optimized value of G/S/G.

3.2.3. Effect of CPW Length

Keeping the G/S/G variations as derived earlier, the CPW length is altered as it is shown in Table 2.

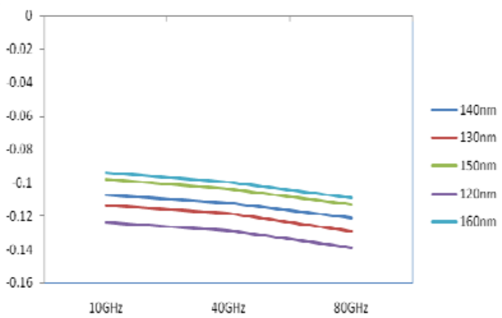
Table 2. Variation of CPW length.

CPW Length	Insertion Loss		
	10 GHz	**40 GHz**	**80 GHz**
3 um	-0.093	-0.0977	-0.1097
4 um	-0.1194	-0.1257	-0.1412
5 um	-0.146	-0.1526	-0.1714
CPW Length	**Return Loss**		
	10 GHz	**40 GHz**	**80 GHz**
3 um	-55.2368	-43.4799	-37.7889
4 um	-34.5904	-33.2651	-31.288
5 um	-28.5954	-28.313	-27.1366

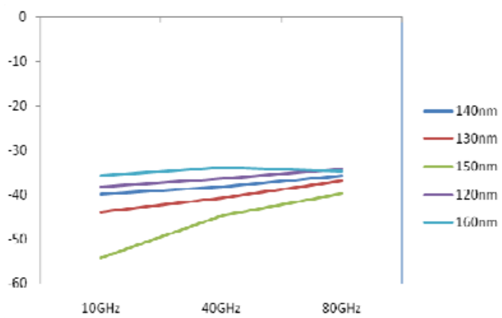
Based on the tabulated values it is observed that 3 μm is the corrected length of CPW for the switch.

3.2.4. Effect of CPW Thickness

The thickness of the CPW also varies the overall impedance of the switch.Hence it is carefuly observed that 50 Ω impedance is observed. The CPW thickness variations are shown in Fig. 3.



(a) Insertion Loss



(b) Return Loss

Fig. 3. CPW thickness variations: (a) Insertion loss, (b) Return Loss of a RF NEMS Switch.

From the above graph it can be estimated that 130 nm give the optimizable outputs for the NEMS switch.As the CPW thickness is being varied the radiations being offered by the transmission is varied thereby producing a change in the parameters of the NEMS switch Silicon dioxide layer thickness is further changed.

3.2.5. Silicon Dioxide Thickness Determination

The final dimesional aspect which may lead to a better switch characteristic is its isolation layer. Hence this isolation layer is varied in a few different dimesions to deduce the best optimized NEMS switch.

Table 3. Isolation layer variation characteristics.

SiO_2 thickness	Insertion Loss		
	10 GHz	**40 GHz**	**80 GHz**
140 nm	-0.1152	-0.12	-0.1305
130 nm	-0.1121	-0.1169	-0.1274
150 nm	-0.1137	-0.1186	-0.127
120 nm	-0.1129	0.1175	-0.1279
160 nm	-0.114	-0.119	-0.1284
SiO_2 thickness	**Return Loss**		
	10 GHz	**40 GHz**	**80 GHz**
140 nm	-51.5165	-43.8378	-38.0895
130 nm	-38.4675	-37.5366	-35.759
150 nm	-43.8837	-40.7257	-36.8914
120 nm	-44.0879	-40.9167	-37.078
160 nm	-36.5603	-37.2946	-32.856

A few carefully selected values [8] of the isolated layer have been portrayed in the form of a table above to bring about the best of the characteritstics in an RF NEMS switch.

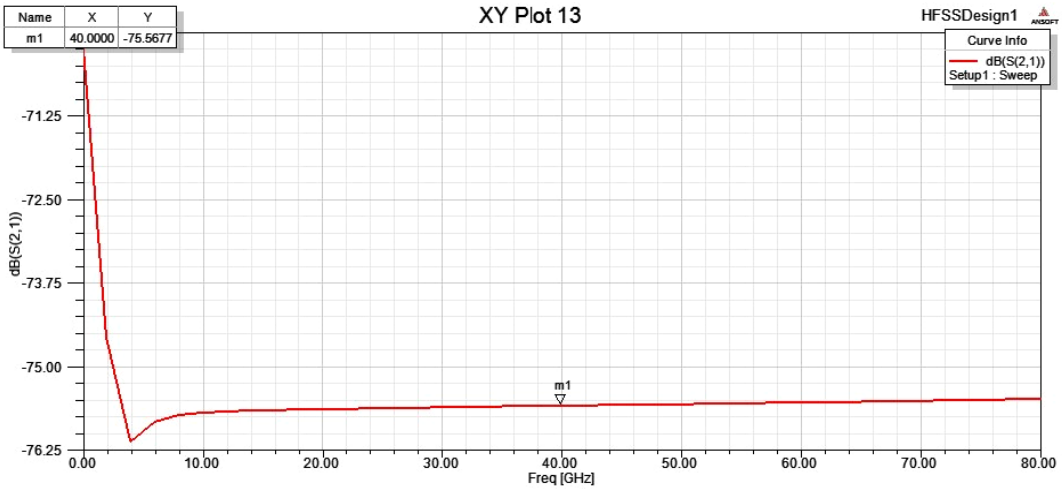
4. Final Optimized RF NEMS Switch

After analyzing various parameters and dimensions a final optimized result is simulated. The optimized dimensions are found out to be:

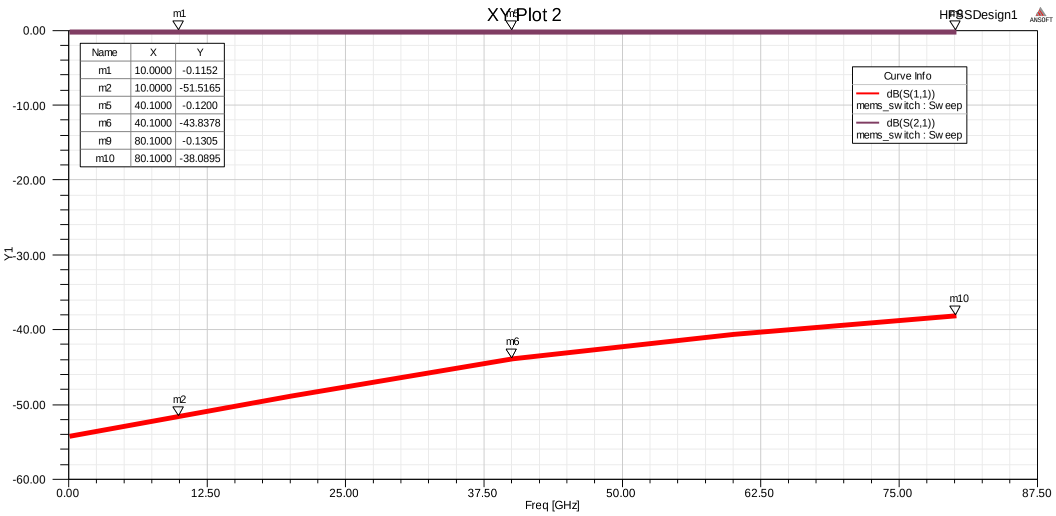
Table 4. Optimized values of the switch.

Parameter	Value
Substrate thickness:	1000 nm
G/S/G	125/210/125
CPW length	3 μm
CPW thickness	130 nm
Isolation thickness	140 nm

Therefore the Insertion loss and the Return loss characteristics of the NEMS switch are as shown in Fig. 4.



(a) Isolation



(b) Down state

Fig. 4. Final Optimized RF NEMS Switch Insertion loss and return loss in down state.

From the analysis performed for the optimized switch characteristics, a return loss of -75 dB and an insertion loss of -0.1352 dB is observed at 80 GHz which is in the RADAR range.

5. Mechanical Analysis

After the electromagnetic analysis of the NEMS switch, it is further analyzed for its mechanical characteristics with Intellisuite software (Fig. 5).

The theoretical value for the pull in voltage is given in (1)

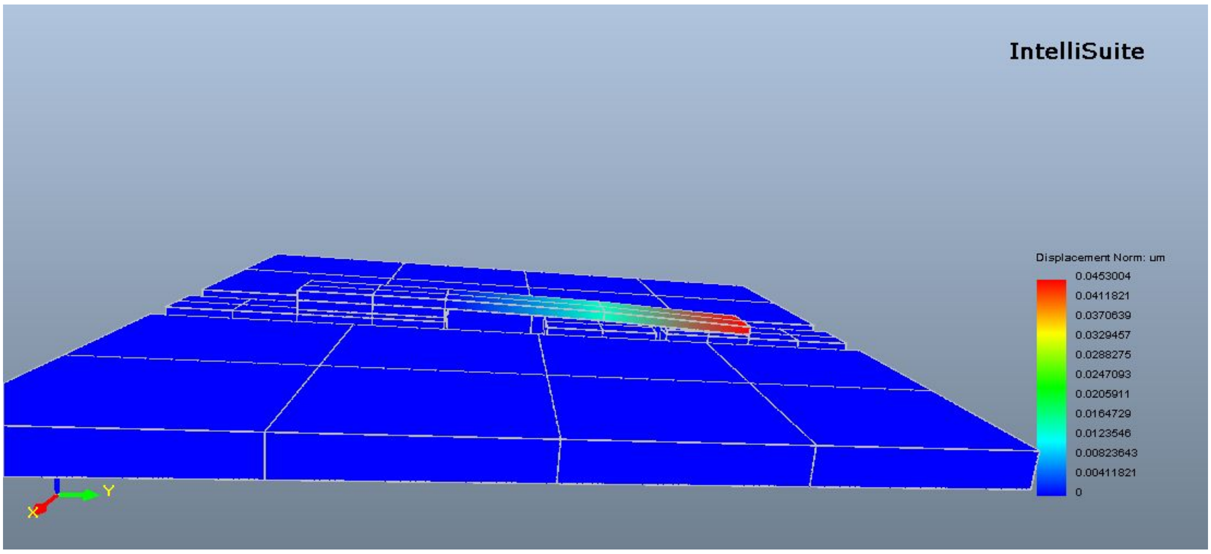
$$V_p = \sqrt{\frac{8\,kg^3}{27\varepsilon_0 A}} \quad (1)$$

where [14, 15] k_s is the spring constant, g_0 is the gap between cantilever and contact area, ε_0 is the 8.85×10^{-12} F/m, V_p is the pull-in voltage, A is the Actuation Area.

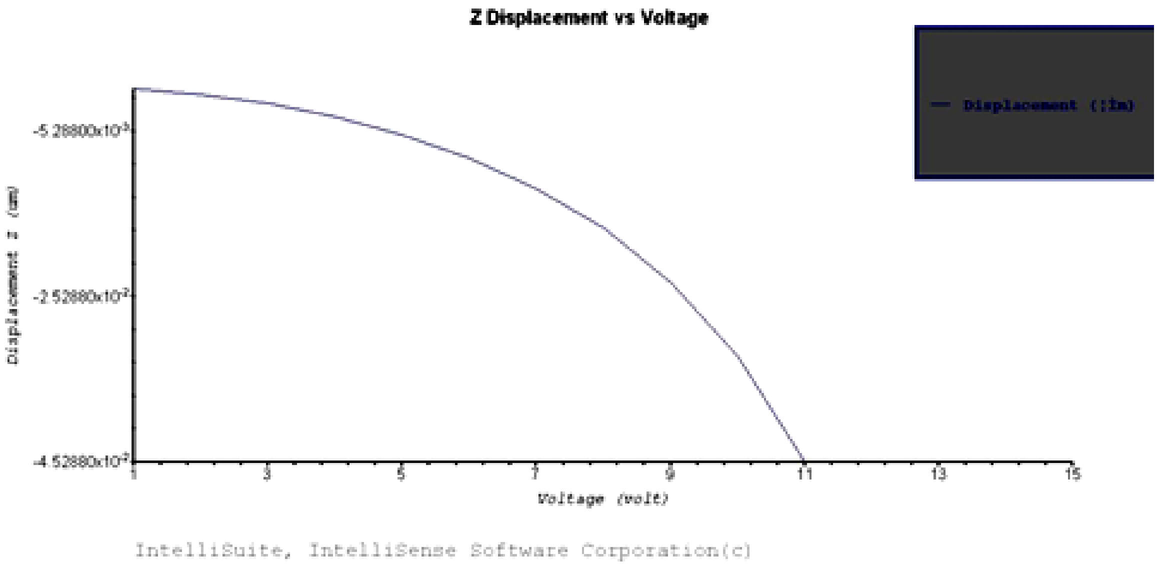
The optimized NEMS switch was built and meshed on FEA tool Intellisuite^{TM} using the module 3D builder and analyzed using TEM module to obtain a displacement and the respective pull-in voltage of 9 V.

6. Conclusion

A high isolation NEMS switch from 0-80 GHz has been proposed. The effect of various parameters is studied and presented. The NEMS switch is optimized for the best performance. An insertion loss values of -0.1305 dB in the down state with return loss of -38 dB and -75 dB of isolation has been observed up to 80 GHz. The obtained range covers many applications of the radar.



(a) Displacement



(b)Pull-in Voltage

Fig. 5. Mechanical Analysis of the RF NEMS Switch: (a) Displacement, (b) Pull in Voltage.

References

[1]. G. M. Rebeiz, RF MEMS Theory, Design and Technology, *John Wiley & Sons,* 2003.

[2]. Zhao Yapu, Stiction and Anti-Stiction in MEMS and NEMS, *Chinese Journal of Mechanics Press*, Beijing, China, Vol. 19, No. l, February 2003.

[3]. Van Caekenberghe, K., RF MEMS technology for radar sensors, in *Proceedings of the International Radar Conference RADAR - Surveillance for a Safer World,* 12-16 Oct. 2009, pp. 1- 6.

[4]. Hector J. De Los Santos, RF MEMS Circuit Design for Wireless Applications, *Artech House,* 2002.

[5]. Norvell, B. R., Caddo Mills, Hancock, R. J., Smith, J. K., Pugh, M. L, Micro Electro Mechanical Switch Technology Applied to Electronically Scanned Arrays for Space Based RADAR, in *Proceedings of the IEEE Aerospace Conference,* 1999, Vol. 3.

[6]. Wen-Ge Yu et. al., Analysis of NEMS switch using changeable space domain, in *Proceedings of the International Conference on Electrical and Control Engineering,* 2010.

[7]. Rainee N. Simons, Coplanar Waveguide Circuits, Components, and Systems, *John Wiley & Sons, Inc.,* 2001.

[8]. Chunbo Zhang and Khalil Najafi, Fabrication of thick silicon dioxide layers for thermal isolation, *Micromech. Microeng.,* Vol. 14 No 6, 2004, p. 769.

[9]. Vijay K. Varadan, K. J. Vinoy, K. A. Jose, RF MEMS and their applications, *John Wiley & Sons Ltd*, 2003.

[10]. J. Rubin, R. Sundararaman, M. K. Kim, and S. Tiwari, A single lithography vertical NEMS switch, in *Proceedings of the 24th IEEE International Conference on Micro Electro Mechanical Systems (MEMS),* Cancun, MEXICO, January 23-27, 2011, pp. 95-98.

[11]. Liam Boodhoo et. al, Energy Reversible Si-based NEMS Switch for Nonvolatile Logic Systems, in *Proceedings of the 8th IEEE International Conference on Nano/Micro Engineered and Molecular Systems (NEMS)*, Suzhou, China, April 7-10, 2013, pp. 558 - 561.

[12]. Sergey Y. Yurish et al, World Sensors and MEMS Markets: Analysis and Trends, *Sensors & Transducers*, Vol. 62, Issue 12, December 2005, pp. 456-461.