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Research paper

Performance of analysis crab leg based RF MEMS switch for defense and aerospace applications

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Abstract

In this paper the design and modeling of capacitive shunt switch for k-ka band applications is presented. The proposed model for this design is the crab leg flexure. In order to reduce the squeeze film air damping, the perforated switch with reduced spring constant is designed. Analysis of designed switch has been carried out on the various parameters of the switch such as damping factor, switching time, quality factor and Eigen frequencies in order to design a reliable switch. The results indicate that the obtained pull in voltage is 3.1V for the dielectric gap of 1µm and spring constant of 2.95N/m^2. Switching time is observed as 1.2µs and 2.15µs for the gap of 1µm and 1.5µm respectively. The capacitance ratio i.e. $C_{down}/C_{up}\frac{C_{down}}{C_{up}}$ is 211.11 for HfO$_2$ and 100.741 for Si$_3$N$_4$. Resonant frequency is obtained as 14.45 KHz. Return loss is calculated as-44.85dB at a frequency of 1GHz and -25.68dB at a frequency of 27.5GHz and insertion loss is obtained as -0.0447db at 1GHz and -1.0379dB at 27.5GHz. The maximum peak isolation is observed as -59.5dB at 1GHz frequency and -71dB at 27.5GHz frequency.

Keywords: *Air damping, Crab Leg Flexure, Eigen frequencies, RF MEMS switch, Shunt-capacitive, Spring Constant, Switching Time.*

1. Introduction

MEMS is a process technology having enormous advantages as less in size [1], less power hungry, highly sensitive, highly controllable and can be fabricated using IC batch fabricating techniques reducing the cost of final product. MEMS is gaining interest almost in all fields due to its inter-disciplinary nature. There are many applications utilizing MEMS technology in RF field such as Switches, Variable Capacitors, Antennae, Filters, Tunable inductors, Resonators. RF MEMS switches are having interest among researchers because of its advantages. As the name suggests, MEMS switches usually work with the assistance of mechanical force, and these strengths are acquired from the electrostatic[2], magneto static, piezoelectric[3], or electromechanical designs. The performance of RF MEMS Switch can be varied by changing materials, Structures and Actuation Techniques.

Usually the radio frequency ranges between 3 kHz to 300 GHz [4].The RF switch operate in RF and mm wave frequencies i.e., 0.1 to 100GHZ.In case of FETs and diodes they require more power to operate, possess poor isolation and the high actuation voltage [5]. RF MEMS Switch can be designed in two different ways. They are series switch and shunt switch.

For a MEMS switch usually there are three main components. The primary component is substrate [6] on which the entire structure is made. For constructing any device or structure, on the top of the substrate, one such process is used called as surface micromachining and if it is constructed inside its structure called bulk micromachining. The most common substrate is silicon and preferably we have to use the silicon with high resistivity.

The secondary component is transmission line[6] which is responsible for the transmission of the signals from the one part to another.

The tertiary component is cantilever[6]. It is a structure which is flexible in movement like a beam and it is responsible for making contacts. The MEMS switch is a leisurely moving beam over coplanar wave guide.

When compared to FETs and PIN diodes, RF MEMS switches are advantageous due to their efficient RF performance and almost zero power consumption[7].Optical excitation and dielectric force gradient excitation schemes are used to actuate the microstructures [8].

Tejinder Singh et.al worked on Ka band applications using series shunt switch with high isolation and low actuation, they have proposed a structure having low spring constant and perforated holes for reduction of air damping[9]· Thetwo types of membranes are made using the crab leg structure. In order to match the actuation of the first membrane second membrane is also designed. Quartz substrate is used in this design with the dielectric layer of HfO2. The k and ka band has the range of 18 to 40 GHz. Here the achieved band width is 30GHz hence it is applicable in that frequency band designator. The paper obtained the isolation of 75dB and actuation of 22.5 V.

Ali Attaran et.al worked on design of the switch RF MEMS of a moving plate with multiple perforations and having low spring constant beam.

For the displacement of 1.5 micro meters the very low pull in voltage of 0.5V is obtained and the lossof is −0.1 dB[10]. The reason for ultra low actuation voltage is using the helix restoring spring with the perforated movable plate. The actuation area is very small, in order to get the less pull in voltage the size has to be reduced.

V. Prithivirajan et.al worked on crab leg structure RF MEMS switch model. Various parameters such as insertion loss, pull down voltage, pull in voltage, hysteresis analysis and isolation have been studied [1]. The pull down voltage is obtained as 17.5V.Silicon substrate with bridge material gold is used here. Here the insertion loss of -0.04 dB is obtained and high isolation is observed around the frequency range of 40GHz and hence it is suitable for the applications of ku band.

Ma Li Ya et.al worked on the new type of design methodology and also the simulation of the RF MEMS switch.The electro mechanical behavior as well as micro wave characteristics has been observed. The virtual simulation has been performed using FEM tool [6].

The pull in voltage has been calculated as 3.53V under the stress condition of around 13.2 MPa. Capacitance ratio is 218.5. The insertion loss has been observed at various frequencies such as 20 and 60GHz.

2. Materials and methods

2.1 Design Methodology

Here we have proposed the crab leg flexure [11] in our design. This structure can be achieved by making some slight modifications to the fixed-fixed structure (Figure 3).

Thigh is the special structure which is added to minimize the peak stress [12]. The figure of crab leg model switch with the rectangular perforations [13] is shown in (Figure 1).

Fig. 1: Schematic of Perforated Crab leg flexure Tool

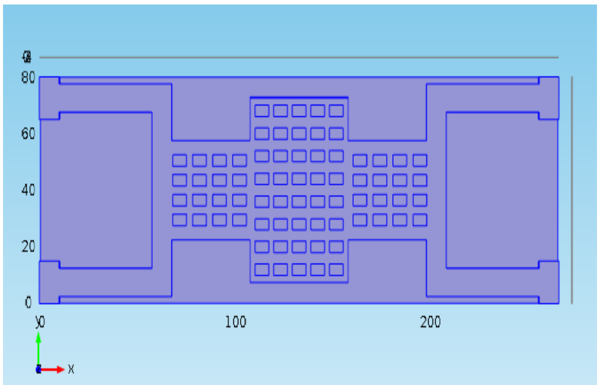


Fig. 2: Two dimensional view of the structure in FEM

In our proposed model the substrate is quartz. The thickness of the substrate is taken around 10 micro meters. The dielectric substance silicon nitride (Si_3N_4) and hafnium dioxide (HfO_2).Various materials such as Gold, PTFE, copper, aluminum and PDMS are used. The gap height is taken as 1um.The design specifications are mentioned in (Table 1).The design analysis has been observed using FEM tool and HFSS (Figure 2).

Table 1: Dimensions of the Switch

Structure	Width (um)	Depth (um)	Height (um)	Material Used
Substrate	245	283.5	10	Quartz
CPW(GSG)	285	244	1	Aluminum
Dielectric	50	75	0.5	HfO_2
Switch Membrane	245	80	1	Gold
Actuation Electrodes	40	35	1	Gold
Signal Line	50	263.5	1	Aluminum
Ground	50	283.5	1	Aluminum

The coplanar wave guide is having the ground signal ground line. The dielectric is placed above the signal line and the air gaps $g_o$is present between the beam and dielectric. The crableg beam is fixed on the two anchors which are on the above of ground plane.

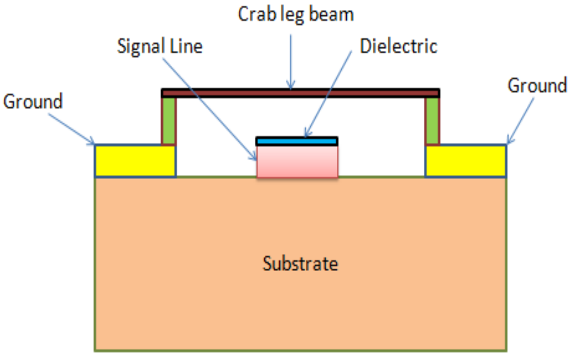


Fig. 3: Cross section of RFMEMS with crab leg structure

The structure is designed using HFSS using the same materials and similar design constraints. The major parameters analyzed in this crab leg structured switch are return loss, insertion loss and peak isolation, where slight change in these values will make an enormous difference in functionality as such of RF band limitations.

In the proposed design, geometrical variations in terms of structure, shape, material, gap and conducting materials have led to good RF performance. The geometrical parameters which are going to be investigated in this model are air gap height (g_o) and conducting material used for CPW line.

2.2. Mathematical modeling

A. Pull-in voltage

A low voltage MEMS switch makes it more convenient for a switch to be embedded into real applications [14]. The pull-in the z-direction K_z, ε_0 which is the air permittivity, the gap between the membrane and the signal line g_0 and the actuation area (A) as given in the equation below.

$$V_{PI} = \sqrt{\frac{8K_z g_0^3}{27A\varepsilon_0}} \sqrt{\frac{8K_z g_0^3}{27A\varepsilon_0}}$$

Pull in voltage obtained for the gold (Au), aluminum (Al) and copper (Cu) are 3.18, 3.009 and 4.0906 respectively.

B. Up State and down state capacitance

The upstate capacitance usually ranges between 0.2 to 0.4 cpp and down state fringing capacitance are less than 0.05 cpp. The upstate and down state capacitance can be calculated as:

$$C_{ON} = \frac{\varepsilon o ab}{g_o + \frac{t}{\varepsilon_r}}$$

WhereC_{ON} is up state capacitance
a= Width of the actuation electrode
b=Length of the actuation electrode.
Down state capacitance is calculated by

$$C_{off} = \frac{\varepsilon_o \varepsilon_r ab}{t}$$

WhereC_{Off} is down state capacitance

C. Figure of merit

The final capacitive ratio can be calculated by ratio of up state capacitance to the downstate capacitance given by:

$$C_{ratio}=\left(\frac{C_{down}}{C_{up}}\right)=\frac{\frac{\varepsilon_o \varepsilon_r ab}{t_d}}{\frac{\varepsilon_o ab}{g_o+\frac{t_d}{\varepsilon_r}}}$$

HereC_{ratio} is also known as figure of merit [4].
$\varepsilon_r$is relative dielectric constant.
Dielectric constant for HfO_2 and Si_3N_4 is 25 and 7.5 respectively.The Up-capacitance for dielectric materials HfO_2 and $Si_3N_4$is 8.29 and 7.615 respectively.
Here we have observed the capacitance values for the dielectric i.e. C_{down} for HfO_2 is 1750.18fF and C_{down} for Si_3N_4 is 767.15fF.

D. Spring constant

For the efficient performance of the switch we need the less actuation voltage and huge isolation [15].Less actuation voltage can be achieved by reducing the spring constant[16], hence it is the important factor of the switch. It can be by using the formula.

$$K= \frac{YWt^3}{l^3} \frac{\mathrm{YWt}^3}{\mathrm{l}^3}$$

Where Y=Young's modulus of the material
t= beam thickness
l= beam Length
w= beam width

Spring constant of three materials such as Au, Al, and Cu has been observed as 2.95, 2.637 and 4.873 respectively.

E. Resonant frequency

Resonant frequency of the device explains about the physical variation of the device when it is put to stress. It is also one of the important parameter in switch calculation [16].

$$f=1.03 \sqrt{\frac{Y}{d}} \frac{h}{l^2}$$

Where f= resonant frequency
d=density.
h= beam height

Resonant frequencies for Au, Al and Cu are calculated as 14.45×10^5, 36.11×10^5 and25.40×10^5 respectively.
Among all the three parameters we considered the gold is observed as the best material on average of the other materials.

G. Switching time analysis

The time taken by the switch in order to reach an ON or OFF condition is measured as switching time of the switch. It is directly proportional to the pull in voltage [17].

$$t_s=3.67\frac{V_p}{w_o v_s}$$

$$\frac{\mathrm{V_p}}{\mathrm{w_o v_s}}$$

Where t_s=switching time
V_p=Pull in voltage
w_o=natural frequency=$2\pi f_0$
V_s=source voltage

H. S-Parameters

Return loss S_{11} is defined as the measure of efficient impedance matching of the devices. It is usually represented as negative number. It is measured in dB.

$$S_{11} \approx -20 \log \left| \frac{-jwC_{up}Z_0}{2+jwC_{downZ_0}} \right| \text{ and for } |S11| < -10\text{db [18].}$$

WhereZ_0=characteristic Impedance of transmission line
$\omega = 2\pi f_0$

Theoretically obtained value for return loss at resonating frequency (27.5GHz) is$S_{11} \approx$ -25dB.
Insertion loss and isolation are represented by S_{21} parameter
When the switch is in OFF and ON state respectively.

$$S_{21} \approx -20 \log \left| \frac{2}{2+jwC_{downZ_0}} \right| \text{ and } f \ll f_0.$$

The value obtained at resonating frequency(27.5GHz) for isolation theoretically is $S_{21} \approx$-72dB.

3.Results

The simulation result below has been observed using the FEM tool. The behavior of the switch and the displacement of the switch observed are various frequency ranges as shown below.

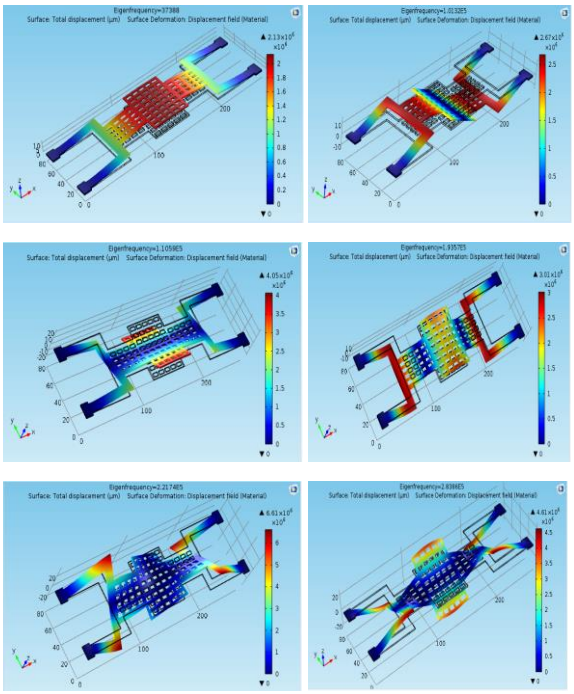


Fig. 4: Eigen frequencies Vs. Displacement Various displacement modes of the switch at the different Eigen frequencies

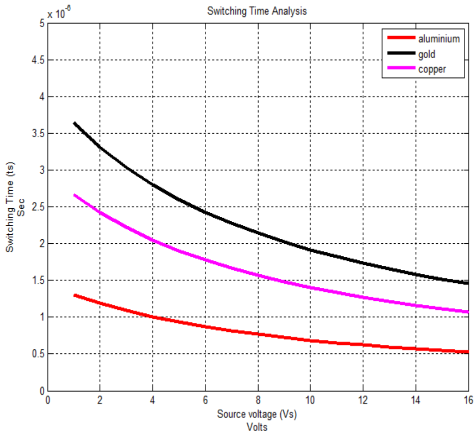


Fig. 5(a): Switching time analysis for gap of 2um

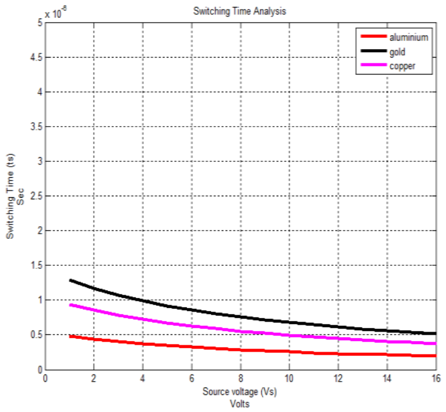


Fig. 5(b): Switching time analysis for gap of 1um

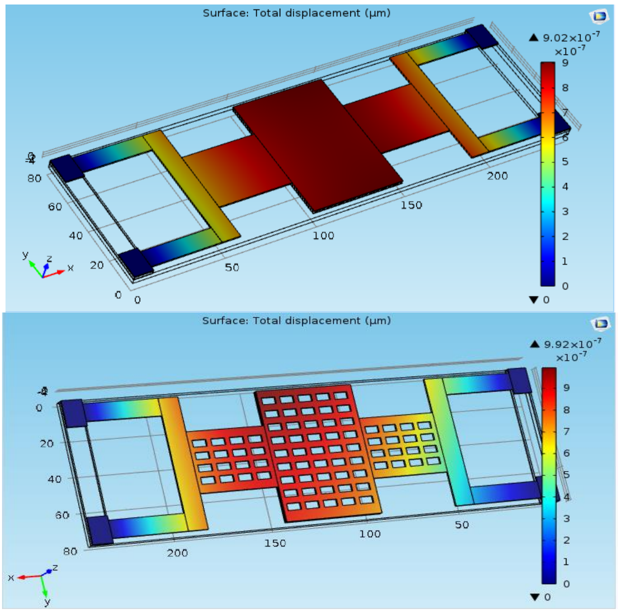


Fig. 6(a): Displacement has been observed at 3.1v for beam without holes and with rectangular holes respectively.

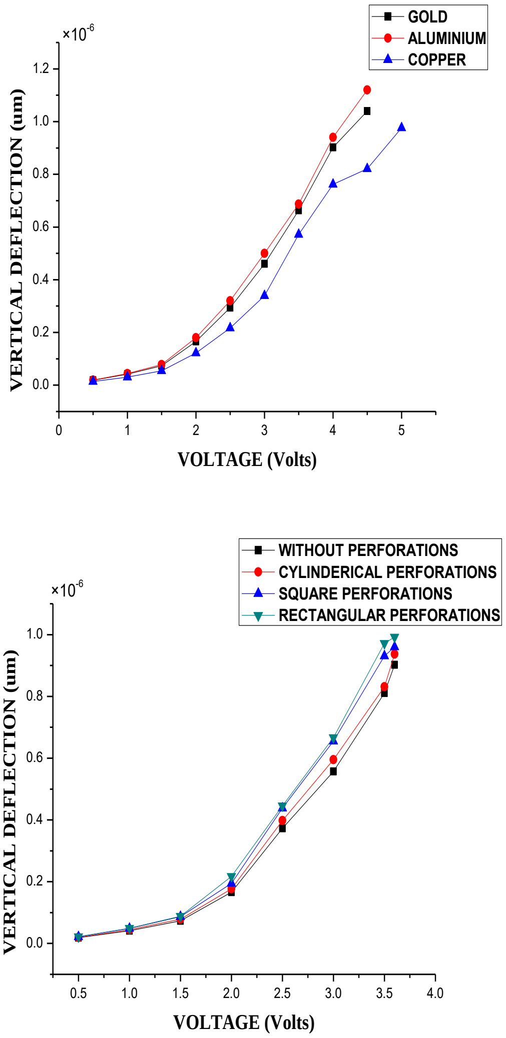


Fig. 6(b): Voltage vs. Displacement graphs for the different materials have been plotted and also using different perforations with gold as a material for membrane.

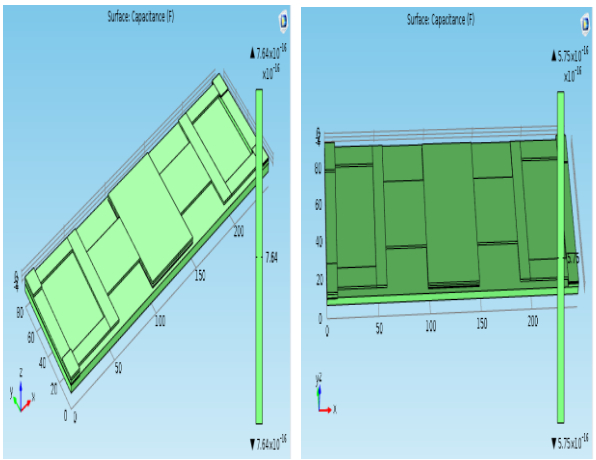
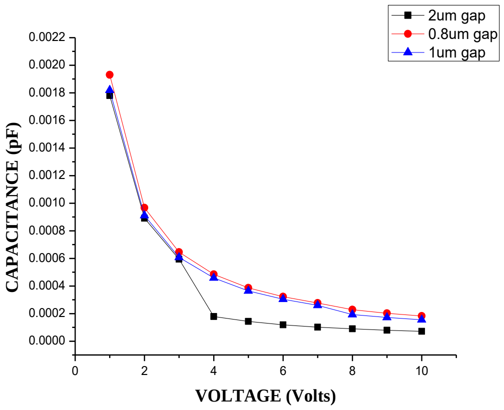


Fig. 7(a): Capacitance is observed at 3.1v for different dielectric materials HfO_2 and Si_3N_4.



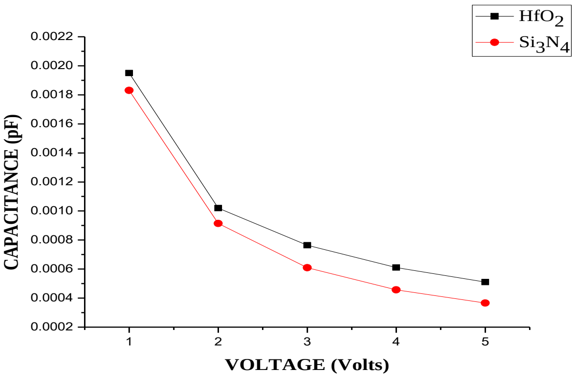


Fig. 7(b): Voltage vs. Capacitance graphs have been plotted using HfO_2 and Si_3N_4.

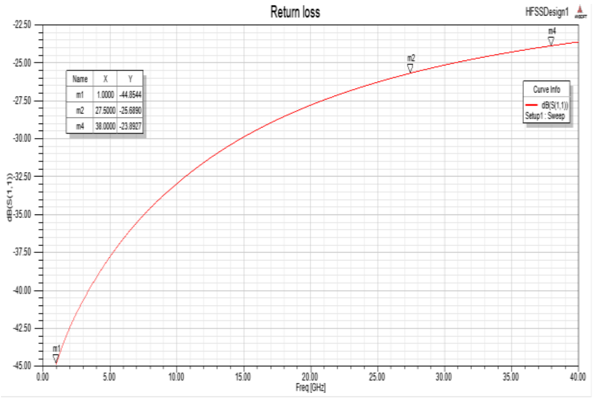


Fig. 8: Simulated down return loss (S_{11}) of aluminum as conducting material for a 50Ω RF MEMS switch using An soft HFSS

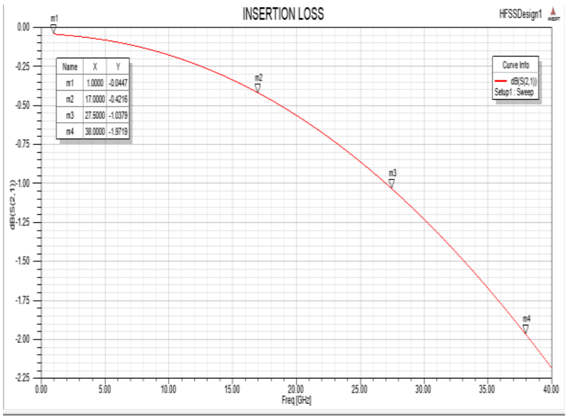


Fig. 9: Simulated down insertion loss (S21) of aluminum as conducting material for a 50Ω RF MEMS switch using An soft HFSS

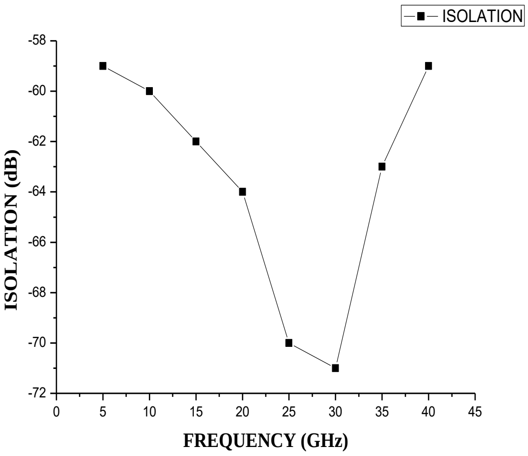


Fig. 10: Simulated down isolation (S21) of aluminum as conducting material for a 50Ω RF MEMS switch using An soft HFSS

4. Discussion

The (Figure 4) shows the movements of the switches at different Eigen values. We can observe that the switching modes at different positions. The switching time analysis has been made using three different materials such as Gold, Aluminum and copper.

The analysis has been made for the various displacements such as 1um, 1.5um and 2.5 um (Figure 5(a)). For 1um gap the switching analysis is observed to be best in gold material followed by copper Even though the aluminum has low pull in voltage than gold and copper taking into consideration all the parameters the best switching speed is gold material (Figure 5(b)).

With square and cylindrical perforations, the displacement of the switch is 0.96 and 0.93um respectively (Figure 6(b)).Displacement of 9.02um and 9.92um has been observed at 3.1v for beam without holes and with rectangular holes respectively using gold material (Figure 6(a)).

Capacitance of 0.764fF and 0.575Ff has been noticed for HfO_2 and Si_3N_4 (Figure 7(a)).Also Capacitance using HfO_2 with different air gaps plotted and observed that when air gap is less than the capacitance is more (Figure 7(b)).

Combined return loss of various materials used in CPW layer in shunt RF MEMs switch configuration. The simulation is done for frequency sweep of 1-40GHz and maximum return loss is observed in case of aluminum. It demonstrates maximum return loss of 44.85db at 1GHz frequency and 25.68db at 27.5GHz frequency. (Figure 8).

(Figure 9) has shown maximum insertion loss of -0.0447dB at 1GHz and -1.0379db at 27.5GHz (resonant frequency) within a frequency sweep of 1-40GHz.(Figure 10) has exhibited maximum isolation of -59.1dB at 1GHz frequency and -71dB at 27.5GHz.

5. Conclusion

The Crab leg structured RF MEMS switch has been presented in this work. Various parameters have been verified in order to check the behavior of the switch and to check the extent of reliability of the switch in present day applications. Capacitance ratio for 1um gap using HfO_2 is 211.11 and using Si_3N_4 is 100.74 which indicate that switching conductivity is well and good. Also pull in voltage (3.1V) is reduced in the case of crab leg flexure by increasing actuation area and decreasing gap between signal line and membrane. The switching time has also been analyzed for 1um gap in the MATLAB which is 1.26us using gold as beam material. RF MEMs switch with 0.5um thickness of dielectric and 1um gap having aluminum as conducting material for CPW transmission line with frequency sweep of 1GHz to 40GHz gives the better results. The isolation is better than 10db in the range of 22GHz to

40GHz i.e. -71dB at 27.5GHz which is nearly equal to theoretical value -72dB. Return loss is better than 10db at lower frequencies i.e. -25.68dB nearly equivalent to theoretical value -25dB and insertion loss is better than 0.3db i.e. -0.0447dB which is good enough for the reconfigurable devices. Hence these switches can be used for K and Ka-band applications (10-30GHz).

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References

[1] V. Prithivirajan et.al, "Low insertion loss RF MEMS Switch with Crab-leg structure for Ku-band application", International Journal of Engineering and Technology (IJET), ISSN: 0975-4024, Vol 5 No 6 Dec 2013-Jan 2014.

[2] Muldavin, J.B.Rebeiz, and G.M.: High-isolation CPW MEMS shuntswitches, part 2: design. IEEE Trans. Microw. Theory Tech. 48(6), 1053–1056 (2000).

[3] Lee, H.C., Park, J.H., Park, J.Y., Nam, H.J., Bu, and J.U.: Design, fabrication and RF performance of two different types of piezoelectrically actuated ohmic MEMS switches. J. Micromechanics Micro engineering 15(11), 2098–2104 (2009).

[4] Gajanan D. Patil, N.R.Kolhare,"A Review Paper on RF MEMS Switch for Wireless Communication",Dept. Of Electronics and Tele-Communication, Government College of Engineering,Aurangabad,India,International Journal of Engineering Trends and Technology-Volume4Issue2-2013.

[5] H. Jaafar, W. Z. W. Hasan ," A comprehensive study on RF MEMS switch", Microsyst Technol (2014) 20:2109–2121DOI 10.1007/s00542-014-2276-7.

[6] Ma Li Ya et.al, "Novel Low-Voltage RF-MEMS Switch: Design and Simulation", IEEE-ICSE2014 Proc. 2014, Kuala Lumpur, Malaysia.

[7] Suraj Gaonkar, Lakshmi .S,"Design, Simulation of Low Actuation RF MEMS Shunt Switches with Electromagnetic Characterization",International Journal on Recent and Innovation Trends in Computing and Communication, ISSN: 2321-8169 3912 – 3918.

[8] Nalluri Siddaiah,D.V.Rama koti Reddy,G.R.K Prasad, Hossein Pakdast, Patcha Satya Srinivas Babu, “Optical and Dielectric force gradient actuation schemes for Excitation of Triple coupled Micro cantilever sensor in mass sensing applications”,ARPN Journal of Engineering and applied Sciences(JEAS), vol. 10, no. 8, May 2015,ISSN:1819-6608.

[9] Tejinder Singh, "Design and finite element modeling of series-shunt configuration based RFMEMS switch for high isolation operation in K–Ka band", J Computer Electron (2015) 14:167–179 DOI 10.1007/s10825-014-0636-2.

[10] Ali Attaran and Rashid Rashidzadeh, "Ultra low actuation voltage RF MEMS switch", Attaran and Rashidzadeh Micro and NanoSystems Letters (2015) 3:7, DOI 10.1186/s40486-015-0024-0.

[11] Avinash Kamble," Comparative Study of Different Flexures of MEMS Accelerometers", International Journal of Engineering and Advanced Technology (IJEAT) ISSN: 2249- 8958, Volume-4 Issue-3, February 2015.

[12] Albert P. Pisano And Young Ho Cho , Department Of Mechanical Engineering And Berkeley Sensor & Actuator Centre, 497 Cory Hall, University Of California, Berkeley, CA 94720(USA), Sensor & Actuator A21-A23(1900) 1060-1064.

[13] Srimanta Baishya, Koushik Guha, " A Modified Capacitance Model Of RF MEMS Shunt Switch Incorporating Fringing Field Effects Of Perforated Beam"Department Of Electronics And Communication Engineering, NIT Assam, K. Guha Et Al. / Solid-State Electronics 114 (2015) 35–42.

[14] Chan, R., R. Lesnick, D. Becher and M.Feng, 2003,"Low-actuation voltage RF MEMS shunt switches with cold switching lifetime of seven billion cycles". J. Microelectromech. Syst., 12: 713-7 19. DOI: 10.1109/JMEMS.2003.817889

[15] Majumder, S.; Lampen, J.; Morrison, R.; Maciel, J. "A packaged, high-lifetime ohmic MEMS RF switch". IEEE MTT-S Int. Microwave Symp. Dig. 2003, 3, 1935-1938.

[16] Somayye Molael and Bahram Azizollah Ganji,"Design and Simulation of A Novel RF MEMS Shunt Capacitive Switch with Low Actuation Voltage and High Isolation", Microsyst Technol DOI 10.1007/S00542-016-2923-2.

[17] Ashish Kumar Sharma and Navneet Gupta," An Improved Design of MEMS Switch for Radio Frequency Applications",Department of Electrical and Electronics Engineering, Bitspilani, International Journal of Applied Electromagnetic and Mechanics 47 (2015) 11–19 DOI 10.3233/JAE-130085IOS Press.

[18] K. S. Kiang, H. M. H. Chong, C. J. Hwang, L. B. Lok, K. Elgaid and M. Kraft, “Development Of A Low Actuation Voltage RF MEMS Switch”, Nano Group, School of Electronics and Computer Science,

[19] University of Southampton, Highfield, Southampton, Hampshire, SO17 1BJ United Kingdom.

[20] Dr. Seetaiah Kilaru, Hari Kishore K, Sravani T, Anvesh Chowdary L, Balaji T “Review and Analysis of Promising Technologies with Respect to fifth Generation Networks”, 2014 First International Conference on Networks & Soft Computing, ISSN:978-1-4799-3486-7/14,pp.270-273,August2014.

[21] Meka Bharadwaj, Hari Kishore "Enhanced Launch-Off-Capture Testing Using BIST Designs” Journal of Engineering and Applied Sciences, ISSN No: 1816-949X, Vol No.12, Issue No.3, page: 636-643, April 2017.

[22] N Bala Dastagiri, Kakarla Hari Kishore "Reduction of Kickback Noise in Latched Comparators for Cardiac IMDs” Indian Journal of Science and Technology, ISSN No: 0974-6846, Vol No.9, Issue No.43, Page: 1-6, November 2016.

[23] A Murali, K Hari Kishore, D Venkat Reddy "Integrating FPGAs with Trigger Circuitry Core System Insertions for Observability in Debugging Process” Journal of Engineering and Applied Sciences, ISSN No: 1816-949X, Vol No.11, Issue No.12, page: 2643-2650, December 2016.

[24] Mahesh Mudavath, K Hari Kishore "Design of CMOS RF Front-End of Low Noise Amplifier for LTE System Applications Integrating FPGAs” Asian Journal of Information Technology, ISSN No: 1682-3915, Vol No.15, Issue No.20, page: 4040-4047, December 2016.

[25] P Bala Gopal, K Hari Kishore, B.Praveen Kittu “An FPGA Implementation of On Chip UART Testing with BIST Techniques”, International Journal of Applied Engineering Research, ISSN 0973-4562, Volume 10, Number 14 , pp. 34047-34051, August 2015

[26] S Nazeer Hussain, K Hari Kishore "Computational Optimization of Placement and Routing using Genetic Algorithm” Indian Journal of Science and Technology, ISSN No: 0974-6846, Vol No.9, Issue No.47, page: 1-4, December 2016.

[27] N Bala Gopal, K Hari Kishore "Analysis of Low Power Low Kickback Noise in Dynamic Comparators in Pacemakers” Indian Journal of Science and Technology, ISSN No: 0974-6846, Vol No.9, Issue No.44, page: 1-4, November 2016.

[28] T.Padmapriya and V.Saminadan, “Utility based Vertical Handoff Decision Model for LTE-A networks”, International Journal of Computer Science and Information Security, ISSN 1947-5500, vol.14, no.11, November 2016.

[29] S.V.Manikanthan and T.Padmapriya “Recent Trends In M2m Communications In 4g Networks And Evolution Towards 5g”, International Journal of Pure and Applied Mathematics, ISSN NO:1314-3395, Vol-115, Issue -8, Sep 2017.

[30] Rajesh, M., and J. M. Gnanasekar. "Constructing Well-Organized Wireless Sensor Networks with Low-Level Identification." World Engineering & Applied Sciences Journal 7.1 (2016).