ISSN ONLINE (2395-1680)
DOI: 10.21917/ijme.2015.0004

DESIGN AND SIMULATION OF LOW ACTUATION VOLTAGE PERFORATED RF MEMS SWITCH

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Abstract

RF MEMS switch is widely used for area of communication circuits systems and it enables identification of micro size mechanical switches entrenched in electronics devices. The IC Technology for improving performance compatibility mandatory the low actuation voltages switches in RF application and microelectronics mechanical system. The MEMS technology is reduced the actuation voltages, spring constant, and squeezes film damping. The Fixed-fixed beam is capacitive shunt type switch. The shunt switch useful at the higher frequencies, it's reduced the parasitic and increased RF power. Fixed – Fixed beam is an element that is fixed at both ends. The electrostatic actuation process is used to pull down the beam towards electrode. The electrostatically process is low power consumption process with higher flexibility displacement output. The paper explains the concept of low of actuation voltage, higher flexibility; lower the squeeze film damping, higher switching speed. The serpentine square flexures or meanders are used to get higher displacement of switch. These all requirement are achieved by using perforation technique in switch. The various type perforated switch is designed and simulated. The comparative study of perforated RF MEMS switch has been done in this research paper. The perforation size 1μm-4μm is used in switch. The comparison analysis has been done with design and simulation of switch. For designing and simulation of switch we have used the software- COMSOL® MULTIPHYSICS 4.3b.

Keywords:

Fixed-Fixed Beam, Material, Meanders, Electrostatic, Low Actuation Voltage

1. INTRODUCTION

The development of Micro-Electro-Mechanical Systems (MEMS) technology in current decades has resulted in advancement to the automotive, communication and medical industries where size and mass diminution have improved performance of microsensors and microactuators, such as accelerometers for inertial measurement, mass-flow sensors, bio-chips for microfluidics, RF switches and automotive pressure sensors [1]. Microelectromechanical Systems (MEMS) switches optimized to work at Radio Frequencies (RF) have been a primary focus of intensive research both academia and industrial organization. RF MEMS switches have replaced the conventional GaAs FET and p-i-n diode switches in RF and microwave systems, because of their negligible power consumption of a few μ watts; low insertion loss, high isolation, and much lower inter modulation distortion, small footprints, low cost, and light weight [2]. Micro Electro Mechanical Systems (MEMS) capacitive type transducers are used to sense external mechanical excitation such as force, acceleration, as a change in capacitance. It requires electrical energy and this energy is applied as a constant voltage (or) constant charge [3]. The MEMS switches concern like stiction between metal and metal which increases the ohmic resistance which provide losses, charge injection due to a very high electric field at down state is the major problem of this type of MEMS switches [4]. In this paper we have designed and simulated MEMS Fixed-Fixed switch with various shape of perforation (pentagon, triangular, rectangular). Fixed –Fixed is a switch anchored at both end. The perforation concept is used in switch to reduce the actuation voltages and increases switching speed. The density of perforation in fixed volume is almost the same. It also decreases the squeeze film damping. When the voltages are applied on the switch, it shifts to downward corresponding to z-axis and get the various displacements. The perforation geometry used for designed and simulation is triangular, rectangular, pentagon. The switch is provided various z-component displacements at various applied voltages. The switch uses square Meanders which is increases the flexibility. The serpentine meanders and perforation both are techniques used to low actuation voltages and increases switching speed. The pull in voltage is voltage that contact the movable beam and electrode each other. The switch pull down when applied voltage is greater than the electrostatic pull-in voltage, applied between the movable beam and the electrode. In this state (the down-state) incident signals are reflected due to the construction of a low impedance path through the dielectric and the switch to ground. The COMSOL® MULTIPHYSICS 4.3b software is used for design and simulate MEMS switch. The aim and research of this paper is that the design and simulation of switch at low actuation voltage with various geometry of perforation.

2. EXPERIMENTAL

2.1 STRUCTURE OF SWITCH AND PRINCIPLE

The proposed switch having hafnium oxide dielectric material which has the value of dielectric constant is very high. The Fixed-Fixed beam or Fixed-Fixed MEMS switch is fixed on both ends above free gap. The Fixed-Fixed switch all dimensions are in micrometers. The meanders are included in side of membrane to lower down the actuation voltages. The meanders are the present at top end of the membrane to give a proper space for movement. The gap height is of 2μm is maintained between pull down electrode and membrane as it is needed to optimize the pull-down voltage and gap. Otherwise, the membrane may become prone to self-biasing and external vibrations, and then it would not be possible to recover the membrane's position due to elastic recovery forces. The proposed switch is electrostatic actuated by electrostatic force. When a voltage is applied to the pull-down electrode, the membrane connected to the grounds and snapped down the beam. In this the perforation is done on fixed volume with various shapes. The various type of perforation provides large displacement by lowering the mass and reducing the biaxial residual stress. The perforation reduces the principle strain on the membrane at the pull down electrode area. The square meanders are connected to the Fixed- Fixed MEMS switch. The dimensions of perforations are such types:-

Table.1. Dimension of perforation various geometry

Perforation Geometry	Rectangle	Pentagon	Triangular
Dimension	L = 3µm	L = 1µm	L = 1µm
	W = 1µm	W = 1µm	W = 1µm
	H = 2µm	H = 1µm	H = 1µm

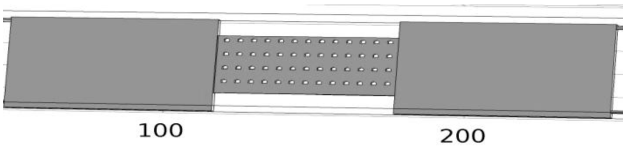

Fig.1. 3D view of pentagon perforation on Switch P_P

In this design serpentine, meanders used to support the membrane which provides the greater flexibility and high switching speed. The electrostatic actuation process induces electrostatic force by the potential difference between movable beam and electrode. The electrostatic actuators can be easily built by many fabrication methods, which are well-suited with most CMOS technologies which are employed in order to manufacture modern analog and digital devices. In the figure, the model perforated MEMS switch is shown. The various types of perforation is applied on the membrane and simulated. The inclusion of perforation of 2µm-3µm the membrane helps to reduce the biaxial residual stress. The membrane is reliable in terms of switching life due to the flatbed internal structure. The membrane does not bend when pulled in towards the signal line. The bending occurs only meanders which reduce. The perforations help in reducing the principle strain on the membrane at the pull down electrode area. The diameter of the perforation in the membrane should be less than $2g_0$, so as not to affect the capacitance.

2.2 SWITCH SPECIFICATION

The proposed switch is designed in environment of combined multiphysics, COMSOL MULTIPHYSICS 4.3b is used to compute the displacement, low actuation voltage and tip displacement

2.3 ACTUATION MECHANISM

The proposed switch is used electrostatic actuation mechanism to design the membrane, the load on the membrane is shifted toward the ends, and it has meanders to lower the overall spring constant *k*. The load is distributed because of the ribs around the edges of the membrane. The residual stress component can be neglected during calculation due to the stiffness of the membrane. The actuation voltage VPI of a MEMS switch is given by,

$$V_{PI} = \sqrt{\frac{4C1B}{\varepsilon_0 L^2 C^2 \left(1 + \frac{c^3 g_0}{W}\right)}} \tag{1}$$

2.4 SIMULATION OF SWITCH

The design of various types perforated switches using shape of pentagon, triangular and rectangular. The Hafnium oxides material is used to in movable switch or beam. The pull-in voltage or the electrostatic actuation voltage required to pull the membrane down to change the state of the switch can be calculated by Eq.(1). The pull-in voltage is plotted vs. displacement in between the membrane and the signal line is shown in Figures. The switch P_P is shown in Fig.1 the simulated of perforate pentagon switch at maximum actuation voltage 24.1. Fixed-Fixed MEMS switch flexibility, switching speed will be increased and squeezed film damping is reducing due to the perforation is applied on the membrane. The switch P_R is shown in Fig.5 at applied voltages 24.1 volt. The switch P_T represented as shown in Fig.4 z-component displacement at applied voltages 24.1. These all perforated switch applied various voltages due to this switch will be snapped down towards the electrode. The comparative study of various perforated has been done in this research. In all perforated switch the switch initially very low displacement occur when applied voltages is applied. Now to moves the switch beam towards electrode it requires to increases the voltages. As the voltages increaser till 5volt, the value of displacement is very small changes. Now the increasing the value of applied voltages vastly due to this the significantly changes in z-component displacement.

3. RESULT AND DISCUSSION

The comparative study of perforated RF MEMS switch has been done in this research papers. The Table.2 shows all the comparison result for z-component displacement at various applied voltages. In this simulation the density of perforation in fixed and volume is almost same. The compares perforated switches z-component displacement at applied voltages. The problem of stiction in MEMS switches between metal to metal contacts is reduced in this simulation. The perforation is technique which reduced the fringing fields, air resistance and increased switching speed. The design, numerical analysis & simulation result show that the perforated switch P_T is provided minimum 0.0938µm z-component displacement at pull in voltage. The electrostatic actuation process induced electrostatic force between movable beam and electrode which snapped down the beam towards the electrode. The air gap between movable beam and electrode is reduced by electrostatic force which is induced by applied voltage. The hafnium oxide used in switch material or movable beam. The hafnium oxides possess high dielectric constant and high thermal stability. The Table shows that switch P_T which is triangular perforated is provided -0.0938µm, switch P_P is provided -0.097µm and switch P_R is provided -0.3021µm z-component displacement at various applied voltages. The comparison analysis of perforated switches shows that the maximum gap is reduced between movable beam and electrode is provided by switch P_R and minimum gap is provided by switch P_T. The switch P_P displacement is higher than switch P_T, but lower than switch P_R. The result for high switching speed at low actuation voltage is provided by switch P_R.

Table.2. Results of different perforation with displacement at applied voltage

Switch	Switch P_T	Switch P_P	Switch P_R
Voltage	Minimum z-component Displacement(μm)		
1	-1.4781e-4	-1.5263e-4	-3.8256e-4
3	-1.3317e-3	-1.3753e-3	-3.4531e-4
5	-3.7076e-3	-3.8289e-3	-9.6483e-3
16.1	-0.0398	-0.0411	-0.1103
18.1	-0.0508	-0.0525	-0.1443
20.1	-0.0634	-0.0655	-0.1856
22.1	-0.0777	-0.0803	-0.2367
24.1	-0.0938	-0.097	-0.3021

The Table.2 represented the simulation result in table format at various voltages variation in z-component displacement. The graphical presentation is shown in Fig.2 for switch P_P. These all graphs represented that z-component displacement is continuously exponentially deceases with increases in voltages. This represented the beam will go towards electrode or ground. The electrostatic force act on beam and snapped down the beam.

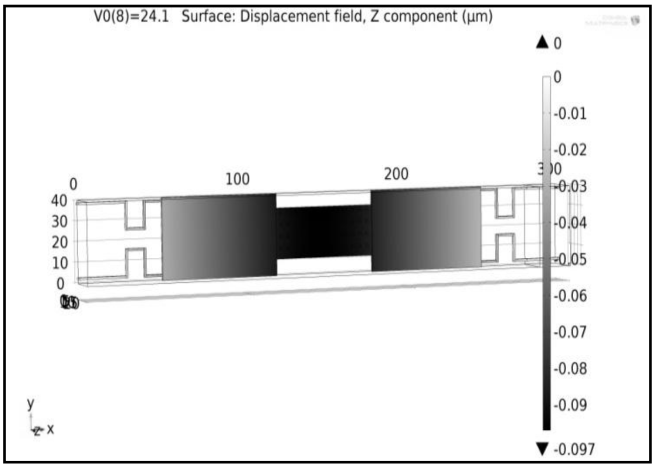

Fig.2. Schematic Simulated 3d structure of Switch P_p

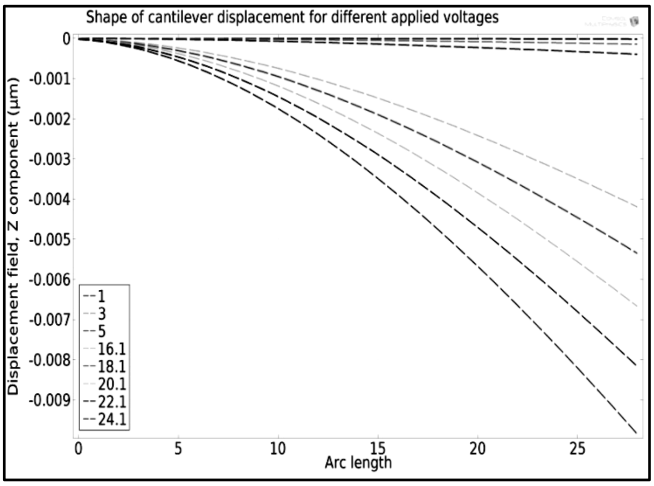

Fig.3. z-component displacement with arch length at various voltages for Switch P_P

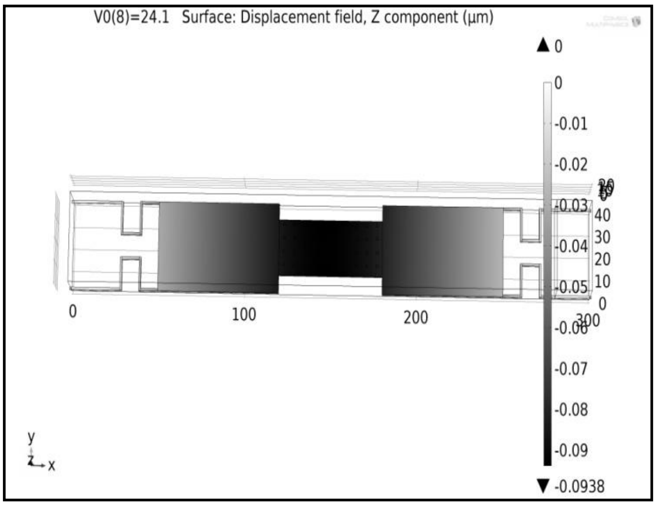

Fig.4. Schematic Simulated 3d structure of switch P_T

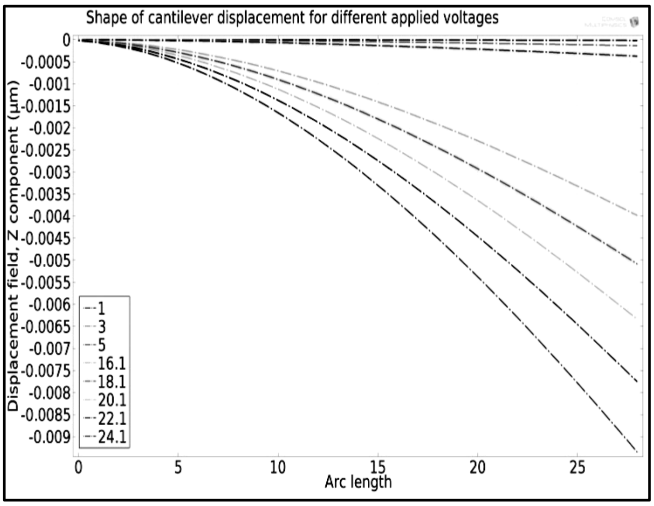

Fig.5. z-component displacement with arch length at various voltages for Switch P_T

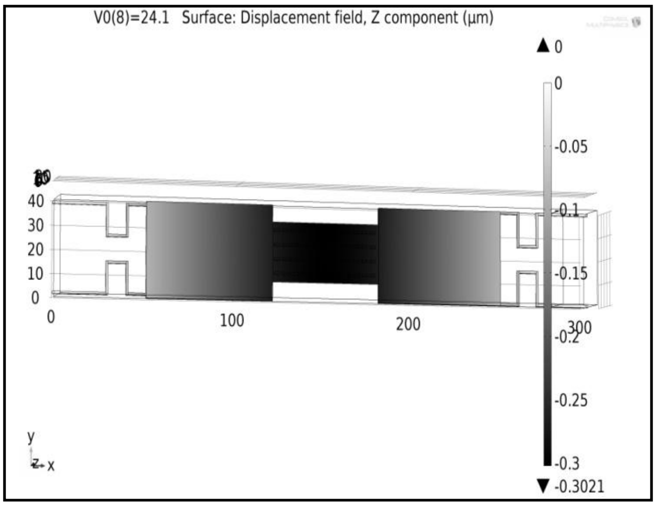

Fig.6. Schematic Simulated 3d structure of Switch P_R

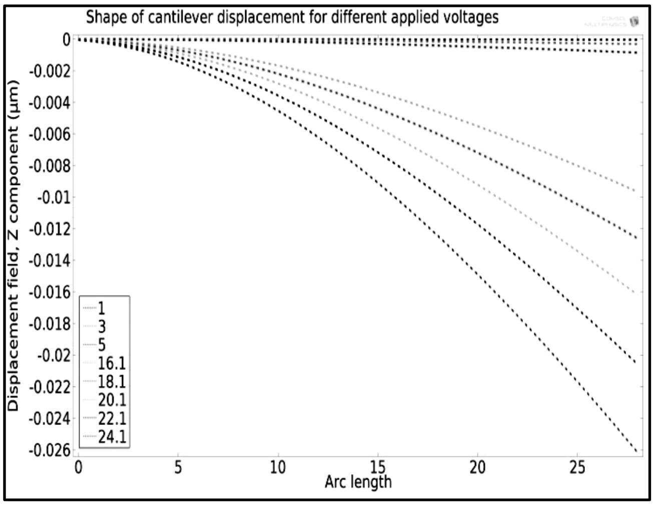

Fig.7. z-component displacement with arch length at various voltages for Switch P_R

4. CONCLUSION

The conclusion of this research paper is that the design and simulation of perforated switch P_R provides maximum displacement-0.3021μm at pull in voltage 24.1. The switch P_T provides very less displacement -0.0938μm at the pull in voltage or maximum voltage 24.1. As the result Fixed-Fixed switch is more flexible when it is perforated with rectangular geometry and increases the switching speed. The hafnium oxide posses are very high young's modulus due to this thermal stability and switch speed of switch increases. The perforated MEMS switches operate at low actuation voltages than other capacitive shunt switches and gives maximum z-component displacement. This result of outstanding RF MEMS switch P_R can be used in low power and low actuation voltages application

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