DESIGN AND ANALYSIS OF RF MICROELECTROMECHANICAL SWITCH FOR COMMUNICATION APPLICATIONS

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***Abstract:** The increased growth of the applications of RF MEMS switches in modern communication systems has produced an enlarged need for their accurate and efficient models. This paper deals with a relatively new area of radio-frequency (RF) technology based on microelectromechanical systems (MEMS). RF MEMS provides a class of new devices and components which display superior high-frequency performance relative to conventional (usually semiconductor) devices, and which enable new system capabilities. RF MEMS Switches with high reliability, low activation voltage, low insertion loss and high isolation are needed for high performance applications of Microwave and communication engineering. This work focus mainly on improving enforcement and reliability of RF MEMS Switch. The intended design be composed of mechanical structure with micro cantilever beam and capacitive contact type. RF MEMS Switch is designed and simulated in COMSOL Multiphysics, Finite Element Analysis (FEM) Tool. The Switch needs to associate or separate RF (Radio Frequency) Transmission line or some other RF microcircuitary network. The exchanging activity depends on electrostatic power incited between two electrodes of the design. This actuated electrostatic power enables the surface of the cantilever to shaft to do avoidances and the circuit will be shut with the goal that RF line Transmission happens. Deflection of the microcantilever beam relies on the electrostatic power created on the electrodes. This electrostatic power created be affected by the connected voltage over the terminal which should be littler for superior and high dependability criteria.*

Keywords – MEMS switch, modelling, COMSOL, FEM, cantilever.

I. INTRODUCTION

Wireless communication has led to rapid technological advancement and breakthrough in Radio Frequency Microelectromechanical Systems (RF MEMS) technology. By combining high RF performance, low cost, and ultra-low power consumption, RF MEMS devices allows one to discover new architectures and configurations which were not possible with the traditional technology and expand its prospective applications from defense-related products to personal communication devices. The MEMS ohmic switch is one of the most promising MEMS devices and has the same principle of a mechanical moving switch to manipulate an electrical signal.

These types of switches offers superior performance compared to the currently employed solid-state switches. RF MEMS switches exhibit excellent performance in terms of insertion loss, isolation, linearity. Most RF MEMS switches developed in the last decades are vertical switches due to their excellent RF performance (Liu 2010). In last few years many researchers report the ohmic contact RF switches such as Yao and Chang at Rockwell (Yao et al 1995), (Muldavin et al 2001), (Hyman et al 1999), (Zavracky et al 1999), (Sakata et al 1999), (Spasos et al 2010). Generally all the mobile devices works at low voltage, about 4- 5V.Consequently, to operate RF MEMS Switch with high actuation voltage of range 40-100V, a dedicated and complex charge pump circuitry is required (Fujiwara et al 2012), (Ananda et al 2003). To avoid this dedicated large circuitry our design approach is towards the low actuation voltage RF MEMS Switch. This paper focuses on identifying operational reliability issues, proposing model for design optimization and control methods to reduce factors that affect the lifetime of the devices. Here we present a metal-contact RF MEMS switch design which focuses on Small-size with optimized geometrical structure, Low actuation voltage, High RF-performance, and High reliability and lifetime.

The mechanical and electrical characteristics of RF switch significantly depend on its structural parameters, so it's important to design and optimize the structure of the RF switch. RF switch with optimized cantilevered beam structure has lower actuation voltage, higher dynamic stiffness (Rebeiz et al 2001). (Liang et al 2005) shows that a non-uniform beam may have a lower pull down voltage than a uniform beam. One end of it is fixed; the other end is covered with a metal-layer to open/connect the microwave signal line. Here we use two types of metals for the switch contact; bottom electrodes are made from gold and the movable top contact is made from the gold-nickel alloy (good corrosion resistance in oxidizing conditions).

II. MATERIAL SELECTION

Substrate is the main thing for any fabrication so the material selected for fabrication plays a major role. A flat microscopic object on which the micro-fabrication takes place is the substrate and here in our design we have selected silicon as substrate material. The popularity of silicon is because of the following conditions:

1) Silicon is abundantly available and also is mechanically stable.
2) It can be integrated into electronics on the same substrate.
3) It has high melting point and hence remains stable even at elevated temperature.
4) Silicon wafers are extremely flat and thus suitable for building microstructural geometry and hence offer greater flexibility in design and manufacture.

To design RF MEMS switch, selection of dielectric, plays an important role. One is Silicon Nitride (Si_3N_4) which has many superior properties that are attractive for MEMS and microsystems. An excellent barrier to diffusion of water and ions like sodium, ultra-strong resistance against oxidation and etchants, stability over wide temperature range and more or less better dielectric constant made us select

Silicon Nitride (Si3N4) as dielectric material. The material selected for the fixed anchor and the flexible membrane is Aluminum (Al) because it has highest Young's modulus value of E=70.0e9 [Pa] .This is advantageous when stiffness factor is being considered in the design.Based on the material selection we observed that gold and aluminium are the appropriate materials to be used as bridge material in RF-MEMS switchto obtain the desired properties to give best performance of the switch.

III. RF MEMS SWITCH

RF MEMS switches have extremely low insertion loss during the on-state and very high isolation during the-off state. They are very suitable for operation at RF and Microwave frequency region. They are extremely linear and have very low intermodulation products. They consume very little power during actuation and can provide a very high capacitance ratio compared to their counterparts. From an electrical contact point of view the MEMS switches can be two types: a) Capacitive contact, and b) DC contact. RF MEMS Switch comprised of bottom electrode, top electrode, microcantilever beam, anchor**,** RF Line for RF transmission and a pulldown electrode. Electrostatic force is procreated when a certain amount of potential (4V) is applied to the microcantilever. Mentioned paper nonce enhanced design flow of RF MEMS switch. The primary advantage of using this process lies in attaining monolithic microsystem which comprises of electronic and mechanical components are made on the common substrate.

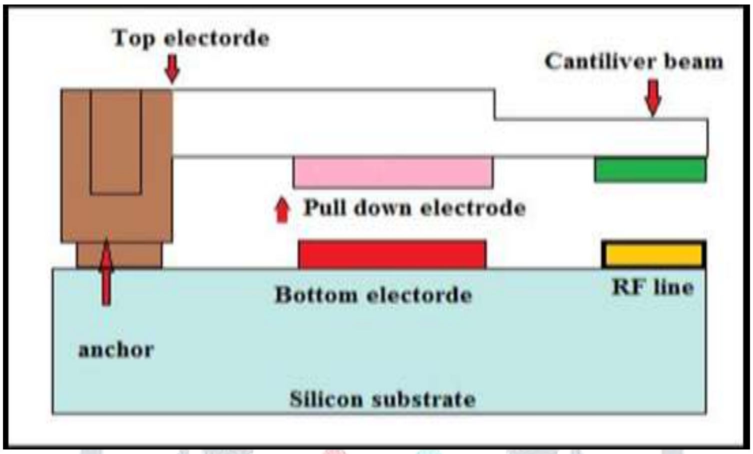


Fig.1. Micro cantilever based RF MEMS switch

IV. SURFACE MICROMACHINING

Surface Micromachining is the process of forming movable structures by placing the structures on initially rigid platforms, then removing the platforms, usually by etching the material away. This is the essential fabrication technique in RF MEMS Switches. It contains deposition and lithographic patterning of various thin films, usually on Si subsrates.

Features are built up, layer by layer on the surface of a substrate.

- Surface micromachined devices are much smaller than bulk micromachined components.
- Nature of deposition process → height of features.
- LPCVD poly-Si films can be only a few microns high.

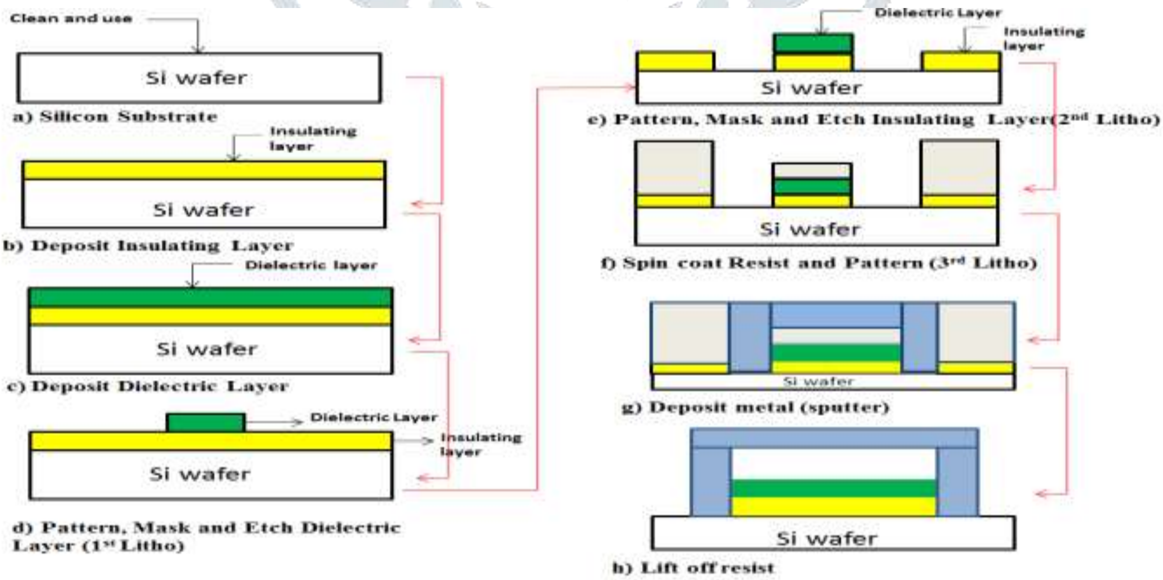


Fig.2. Working flow of Surface micromachining process.

Simple microstructures (beams, gears, membranes, etc.) and complex microdevices (actuators, motors, and sensors) are fabricated on top of a silicon substrate. There are three key challenges in fabrication of microstructures using surface micromachining: control and minimization of stress and stress gradient in the structural layer to avoid bending or buckling of the released microstructure; high selectivity of the sacrificial layer etchant to structural layers and silicon substrate; avoidance of stiction of the released (suspended) microstructure to the substrate.

V. PRINCIPLE OF RF MEMS SWITCH

The RF MEMS Switch consists of an Electrode, a Substrate, Electromechanical bridge or a beam and a flexible membrane. The arrangement of the switch comprises of flexible membrane hanging on the supporting beam which remains in its own default position without showing any change in its position when no actuation voltage is applied.

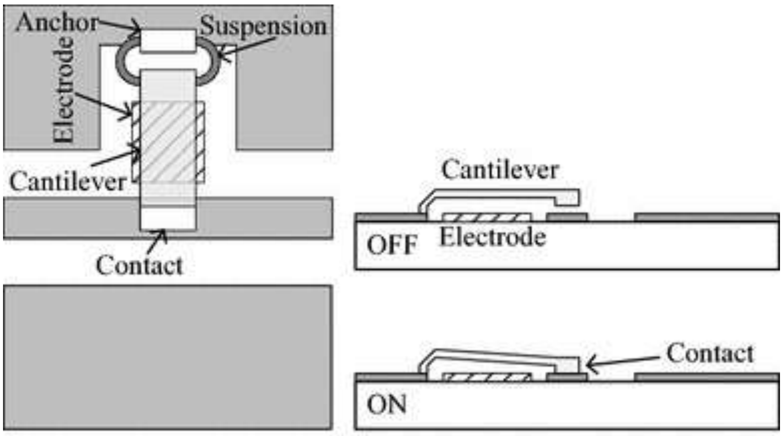


Fig.3. Working of RF MEMS switch in ON and OFF Condition

When a DC actuation voltage is applied between the actuation electrode and the suspended beam, the suspended beam will move downward and collapse on the bottom electrode. This will increase the capacitance in the range of pF, 20-100 times higher than the upstate capacitance. The upstate capacitance depends mainly on the initial gap. The downstate capacitance depends on the dielectric thickness, dielectric constant etc. SiO_2, Si_3N_4, TiO_2 can be used as dielectric for RF MEMS switches. When actuation voltage is applied between the conducting plates of the RF MEMS switch, the flexible membrane sags called deflection and this deflection of the membrane leads to the change in the distance between the conducting plates.This change in distance will again change the capacitance developed within the switch. The changed capacitance with the application of actuation voltage is assumed to be C2.

This capacitance can be calculated from the equation,

$$C = \frac{\varepsilon A}{d} \qquad (1)$$

Here, C=Capacitance between two conductors.

ε=Dielectric constant value of the dielectric present between the two conductors.

A=Cross-sectional area of the plates of the conductors.

d=Distance between the conducting plates.

The capacitance developed according to the position of suspended membrane determines the working of switch, i.e. flow of RF signal or an opposition to RF signal.

$$C = \frac{Q}{V} \qquad (2)$$

C=Capacitance of the device,

Q=Charge stored into the device

,V= Actuation Voltage applied to the device.

As the system changes, the natural frequencies of the system will change along with it.

$$\omega_0 = \sqrt{\frac{k}{m}} \qquad k = \frac{Et^3 w}{4l^3}$$

Natural Frequency Spring Constant

The series resonant frequency of the switch is

$$f_0 = \frac{1}{2\pi\sqrt{LC}} \qquad (3)$$

The critical distance between the electrodes a positive feedback mechanism exists in the electrostatic actuation that makes the beam to bend towards the bottom. An increase in the voltage source increases the force further due to the increase in the charge. The increased force lowers the beam height thereby increasing the capacitance and the electric field.

The Electrostatic force Fe are given by:

$$F_e = \frac{1}{2} V^2 \frac{\epsilon_0 A}{Z_0^2} \qquad (4)$$

Where Fe is the electrostatic force, V is the applied voltage and A is the area of the actuation and z0 is the gap between the electrodes.

For a cantilever beam at equilibrium the force is equal to the restoring force. The pull-in voltage is given by equation

$$V_p = \sqrt{\frac{8KZ_0^3}{27A\epsilon_0}} \qquad (5)$$

Where, k represents the spring constant of the beams; z0 is the initial gap between the membrane and the signal line; ϵ_0 is the permittivity of air, 8.854 × 10í12 F/m; and A is the area of the actuation electrode.

Table. 1. .Design parameters of RF MEMS switch

Parameter	**Dimensions(μm)**	**Materials used**	**colour**
Substrate	210×60	Silicon	Blue
Bottom electrode	60×60	Alluminium	Red
Cantilever beam	210×60	Silicon Nitride	White
Upper electrode	60×60	Alluminium	Brown
Anchor	30×20	Alluminium	Brown
Transmission line connected to substrate	20×20	Gold	Yellow
Transmission line connected to Cantilever beam	20×40	Gold	Green

VI. SIMULATION RESULTS

The proposed RF MEMS Switch is modeled and simulated on COMSOL Multiphysics 5.3a software tool. To allow RF signal flow through the switch, the modeling of switch is being designed as shown in figure. The Stress and Strain values are also analysed in comsol Multiphysics tool. The von-mises stress is also known as the maximum distortion energy criterion. Mathematically the von-mises yield criterion is expressed as

$$J_2 = k^2 \tag{6}$$

Where k is the yield stress of the material.

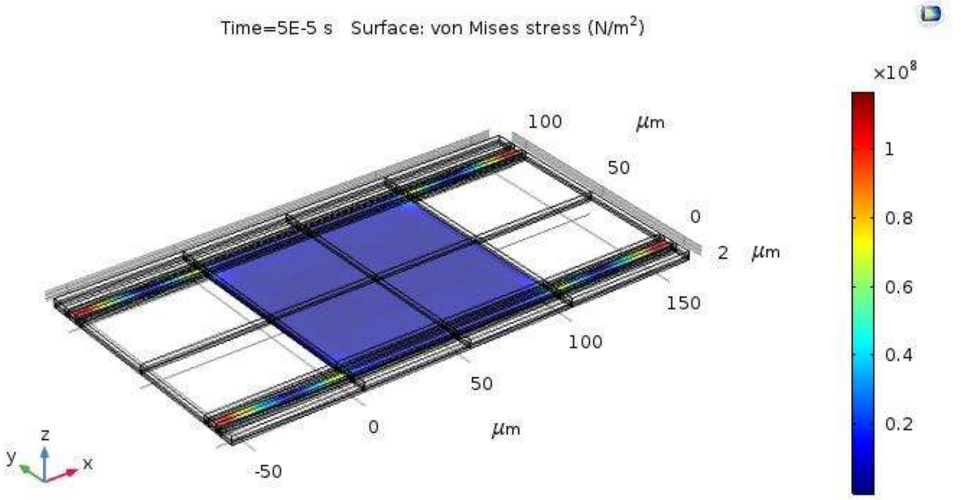


Fig.4. von Mises stress acting on RF MEMS switch

The volumetric strain is the unit change in volume, i.e. the change in volume divided by original volume.

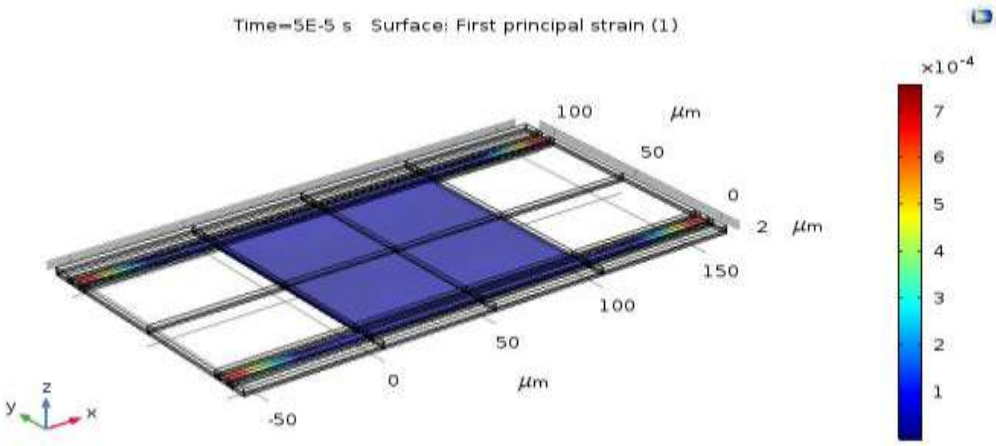


Fig.5. Principal strain of RF MEMS switch

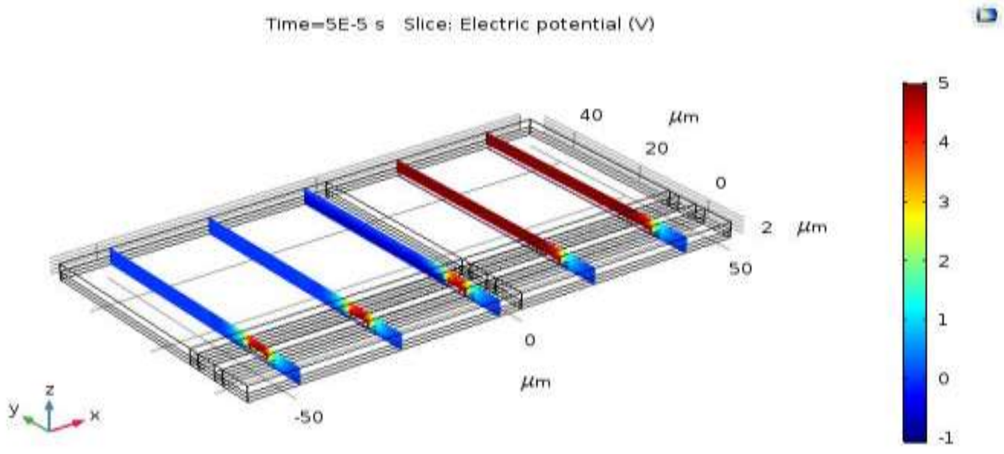


Fig.6. Electric Potential of RF MEMS switch

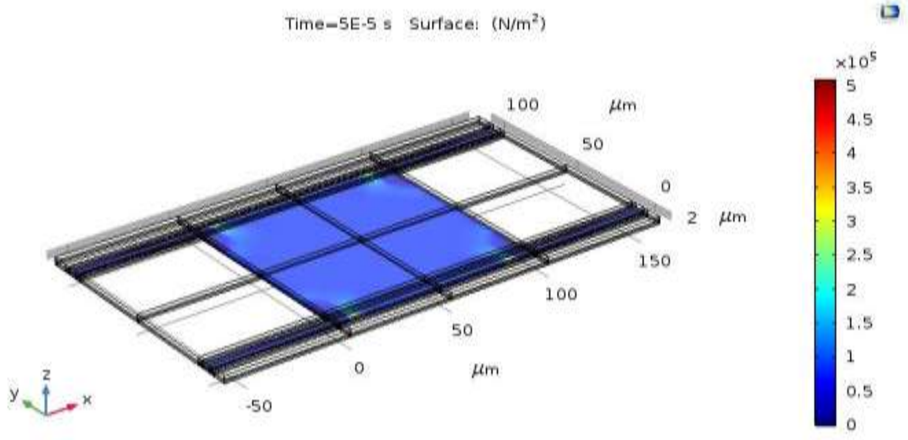
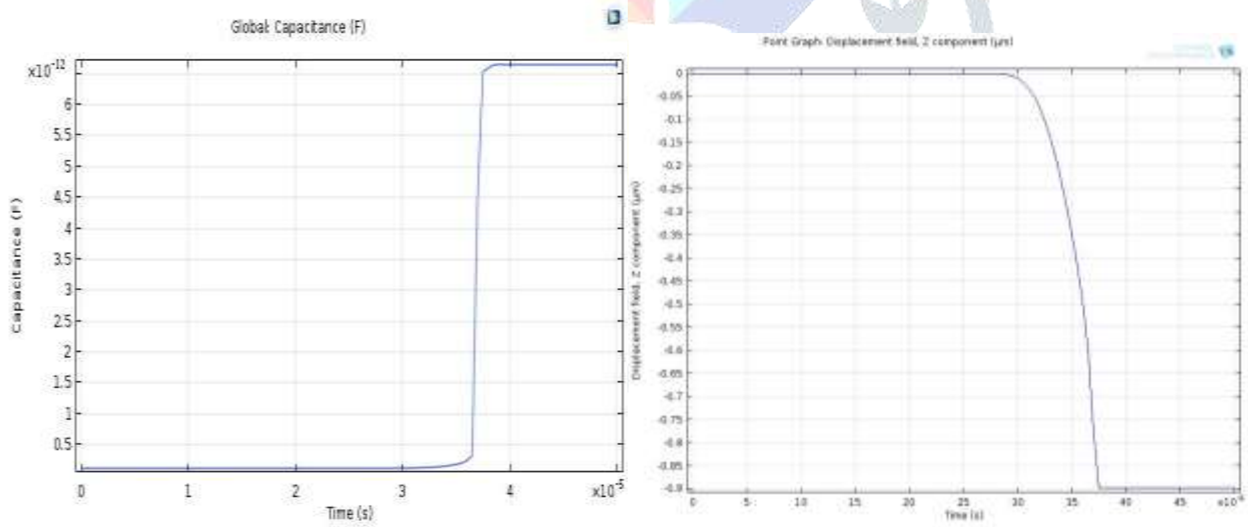
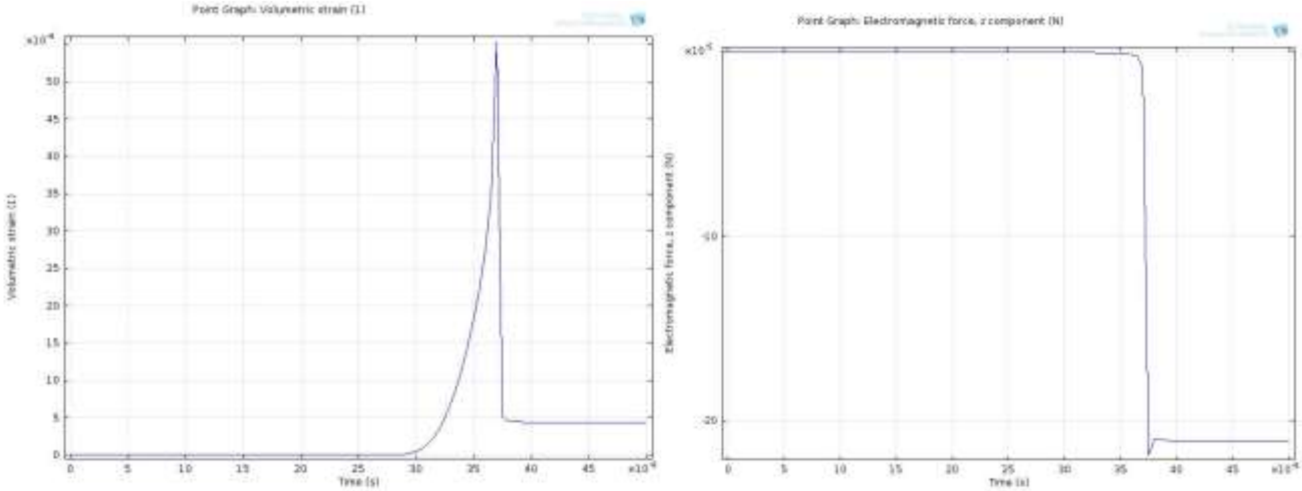


Fig.7. Displacement of RF MEMS switch



(a) (b)

Fig.8. (a) Capacitance of RF MEMS switch. (b) Total displacement switch



(a) (b)

Fig.9. (a) Volumetric strain of MEMS switch. (b) Electromagnetic force in Z direction

By using specified dimensions of the RF MEMS switch, when the simulations is worked out on COMSOL Multiphysics 5.3, it shows that the RF frequency which can be allowed to flow through this optimized switch design is found to be 153MHz and the displacement is 0.005 µm for the flexible membrane when it deflected down towards the dielectric. The simulated results are plotted in frequency and time domain as well. The Maximum applied force is 1.4x10^-8 Kg obtained from simulation. Whereas the theoretical value is 1.6x10^-8 N which implies the simulated results are 97% accurate to theoretical values. Moment of Inertia obtained from simulation is about 6.25x10^-22 m^4. The deflection of microcantilever is 7.203x10^-11m.

VII. Conclusion

The methodology used to present an optimized design of RF MEMS capacitive switch is prescribed in this paper. Since we intend to design RF MEMS switch which helps in allowing and suppressing the RF signal flow through out the switch, the frequency of the signal carried out after simulation is 172MHz. From the results obtained the switch activated with in less time and with low actuation voltage. So, this RF MEMS switch with low actuation voltage and high spring constant can be used in many RF applications.

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