Cantilever RF MEMS Switch

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Abstract: This paper is about the RF (Radio Frequency)-MEMS (Micro-Electro-Mechanical-System) Cantilever switch. The advantage of Cantilever RF Switch over the existing PIN (P type intrinsic N type) Diodes and Field-Effect-Transistors Technologies regarding size, Isolation, power and Insertion loss, and effects of Pull-in voltage on the deflection of the switch is studied. Here cantilever MEMS switch RF characterizations and isolations are discussed. The influences of air gap on isolation, influences of beam thickness on isolation are also discussed by the analysis of various Cantilever RF MEMS Switches. In a Cantilever RF MEMS switch the fixed element at one end is beam and it is free on another end. The fixed beam undergoes electrostatic actuation process and it gets deflected from an original position. Here the electrostatic force is directly proportional to the z-component displacement produced in the beam. The cantilever works as a switch which operates as ON or OFF.

Keywords: ***Air gap, FET, PIN, RF MEMS***

I. INTRODUCTION

The Radio Frequency MEMS that is Micro Electro Mechanical System are in discussion due to its performance Characteristics. It is possible in MEMS technology to fabricate electromechanical as well as microelectronics component into a small single chip. Some advantages like low spring constant, high working frequency are achieved due to the reduction in dimension of electromechanical systems offers advantages such as and hence decrease in power consumption is observed[2].

Recently MEMS technology plays very important role in designing micro devices and so sensors and actuator are also designed using MEMS. MEMS Switches comprise vital part of many high frequency systems and so they are used for power delivery or signal transmission in portable wireless, Radar or satellite communication systems [5]. These Switches have great advantages over their solid state counterparts, even on the characteristics like, low insertion loss, high isolation, low power consumption, high OFF- state isolation and the most important is the micrometer size of MEMS.

The generation today requires very small size of technology and due to the above advantages the RF MEMS switches are dominating over the existing switches like PIN diode switch, FET switch, etc. The fabrication process of MEMS as compared to CMOS technology is compatible. So, it is easy to interface this switches to the required circuit. RF MEMS switches operate on very high frequency that is in range of GHz and so they are used to make and break contact between the transmission lines. So these are also used in Wireless Communication and satellite communication due to its high frequency operation. Not only in communication, but widely used for military applications, mobile phones, etc. MEMS switches basically have advantages of mechanical as well as semiconductor Switches together and has some great advantages. Characteristics like RF Circuit Configuration, Mechanical Structure and Contact form are taken under consideration for classification of MEMS Switches [5].

Basically depending on switch contact perspective, there are two types of Cantilever switches based on the Applications of MEMS technology point of view-

- Series Contact Switches.
- Shunt Capacitive Switches.

1.1. SERIES CONTACT SWITCHES

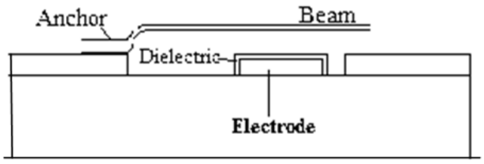

Fig.1. Series Contact Switch

The basic structure of a MEMS contact series switch is its conductive beam suspended over the transmission line. An electrostatic force on the beam is exerted by DC bias, which lowers the beam across the gap and the open ends of the transmission line shorted. When the DC Bias is removed, the beam returns to the suspended position due to spring restoring force in the beam.

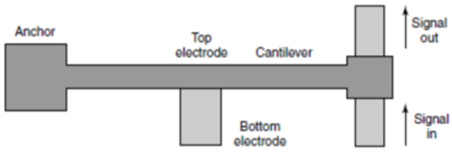

Fig.2. Schematic view of Cantilever Series contact Switch

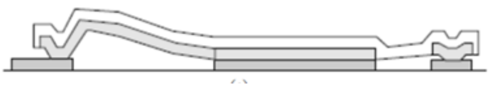

Fig.3. ON state switch position

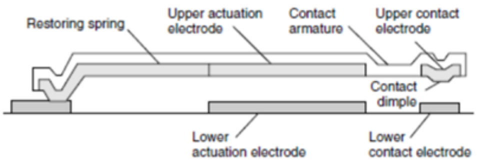

Fig.4. OFF State Switch Position

1.2. SHUNT CAPACITIVE SWITCH

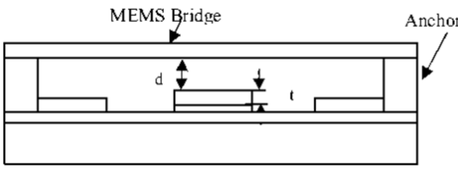

Fig.5. Shunt Capacitive Switch

Fig.5 shows Shunt Capacitive Switch. In these switches beam that is grounded is suspended over a dielectric pad on the transmission line. When the beam is in up position, the line dielectric air beam has capacitance of the order of approx. 50 pF, which converts to a high impedance path to ground through the beam. However the induced electrostatic force pulls down the beam which is to be coplanar with the dielectric pad when a dc voltage is applied between the transmission line and the electrode, resulting in lowering the capacitance to pF levels, impedance of the path through the beam for high frequency (RF) signal and shorting the RF to ground [8].

The insertion loss is lower in capacitive switch than 1.2 dB up to 40 GHz, extracted up-state capacitance is 30 PF and isolation is 1.3dB at 1GHz, 26dB at 20GHz, and 27dB at 40GHz. As one end is free in cantilever type switch, it requires lower actuation voltage compared to Air bridge MEMS switch.

2. CANTILEVER BEAM

There are basically two types of Cantilever Beam.

- Fixed Beam: The beam is fix at both the ends. By applying the voltage in the middle of the beam we can get displacement of the beam and same is by applying the load pressure in the middle. As the applied voltage is increased the displacement is maximum in the middle of the beam.

- Cantilever Beam: end of the bean is fixed while the other one is free. We get the displacement of beam by applying the load or pressure to free an also by applying voltage at the free end. As the applied voltage is increased the displacement is maximum at the free end of the beam.

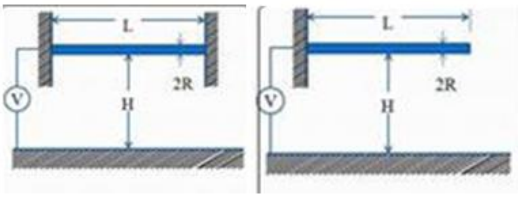

Fig.6. a) Fixed Beam b) Cantilever Beam

If the cantilever beam is to be used as an actuator we must know the pull-in voltage, hold down voltage, spring constant required for cantilever and the resonant frequency for cantilever. Also switching time should be taken under consideration. The parameters that are required to do so is known by studying the Actuation Voltage [8].

RF Performance

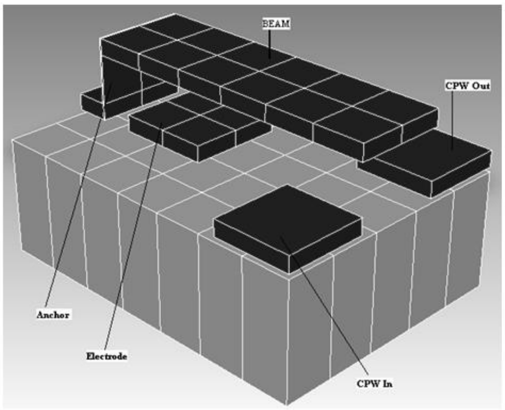

Fig.7. Solid Cantilever Switch

2.1. ACTUATION VOLTAGE:

The working of the cantilever switch depends on the applied electric field to the electrode V, because of this applied field the electrostatic force F is exerted on the beam, this electrostatic force is measured as in equation

$F = \frac{\varepsilon_0 A V^2}{2g^2}$, $F_r \propto K_t.\Delta x$ (1)

Where, V is applied voltage, A is contact area between electrode and beam & g is the deflected gap between electrode and the beam, and Kt is the spring constant.

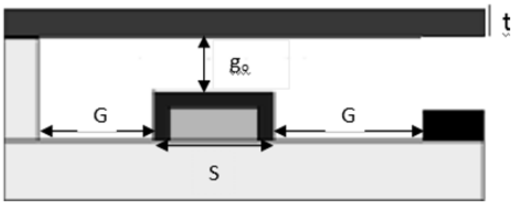

Fig.7. Side view of Cantilever Switch

The applied voltage is directly proportional to the electrostatic force exerted on the cantilever beam. When this force increases the beam tends to pull down towards the electrode and so the gap between the beam and the electrode decreases. When there is increase in applied voltage at a certain level, the electrostatic force is greater than the restoring force exerted by the anchor. At this applied voltage the beam is pulled down towards the electrode, which completes the path allowing the signal to flow from input to output. So the switch is ON[10]. The Applied voltage where the beam is pulled down is called as Pull- in Voltage Vp.

$Vp = \sqrt{\frac{8K_t g_0^2}{27\varepsilon_0 A}}$ (2)

Thus, to reduce the actuation voltage, either reduce the spring constant of beam or reduce the gap height or increase the area of electrodes. However, reduction in gap height shall compromise the isolation aspect and RF performance parameters. Reduction in spring constant of cantilever beam can be achieved by using low density material, by increasing the cantilever length of beam, by using lesser thickness of beam or by reducing the anchor width.

2.2 SWITCHING TIME:

The electrical resistance and mechanical displacement of the switch is measured as a function of time. The closing time depends on the actuation voltage and the opening time depends on the mechanical properties of the switch. By scaling the MEMS devices the switching time is also scale downs, as

$ts \approx 3.67Vp/Vs\omega0$, $f0 =(K/m)$^1/2 (3)

Where ($\omega0$, $f0$) is resonant frequency, Vp is pull-in voltage and Vs is applied voltage.

The Deflection of the beam ΔZ is,

$\Delta Z = 4Fl^3 / Ebt^3$ (4)

Where l, t is beam length, thickness and E is young's modulus.

3. DESIGN OF CANTILEVER RF SWITCH:

3.1. MATCHING COPLANAR WAVEGUIDE:

A coplanar waveguide is a microwave semiconductor device, which works on the principle of Maxwell's equations. A conventional CPW on a substrate consists of a strip conductor between two semi-infinite ground planes on both sides [11].

3.2. ISOLATION:

The isolation of the switch is measured when the switch is in ON state. The measure of the incident power of wave that leaks through the switch is isolation and is given in dB. RF MEMS have high isolation [10][11].

$$IS = -20\log|S_{12}| \quad (5)$$

Where IS is the OFF state isolation of Cantilever Switch and S_{12} is The On state Isolation.

$$S_{12} = 1 / (1+jwC_dZ_0/2) \quad (6)$$

Where, Z_0 is the characteristics impedance of CPW, w is the resonant frequency.

- Influences of Air Gap on Isolation: The Air Gap is directly proportional to the isolation of the switch. As the gap increases the isolation of the switch increases.

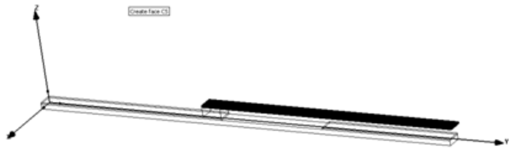

Fig.8. Air gap in the cantilever switch [10]

- Influences of Beam Thickness on Isolation: The thickness of beam is also directly proportional to the isolation.

Fig.8. Beam thickness in the cantilever switch [10]

IV. CONCLUSION:

In this paper we have studied the different types of MEMS Cantilever Radio Frequency switches with its structure. Further how the MEMS Cantilever Radio Frequency switch is superior to other existing devices in comparison with size, required power, isolation and insertion loss. Different types of Cantilever beam, actuation voltage and how the parameters like pull in voltage is important in observing the RF performances. The contact area does not increase after pull down which results in a fast transition which is application for pulse shaping circuits. Also the isolation increases with increase in air gap as well as increase in beam width.

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