A NOVEL SEESAW-TYPE RF MEMS SWITCH WITH MINIMUM STRESS IN MEMBRANE FOR RF FRONTEND APPLICATIONS

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ABSTRACT

In this paper a novel RF MEMS switch design with a seesaw-type movable part to implement a metallic connection across a broken CPW transmission line has been proposed and tested. The switching action is done through two separate pull-up electrodes. For this design with a 5-10 µm gap between the suspended membrane and the pull-down electrodes, applying an actuation voltage of 5-10V, dynamic analysis shows a switching time of less than 10 µs. Unlike in other MEMS switches designed earlier for RF devices the proposed work in this report works with two supply lines switched seamlessly. The bending of the membrane is considerably reduced in this type of switch as the actuation electrodes are in the outer end and the signal lines between the pivot arrangement and electrode. The existing switches implement a single signal line and it is switched on and off but in the proposed switch two supply lines on both sides of the substrate are kept and are switched from one to the other by the see-saw operation of the membrane.

KEYWORDS

Dual supply switching, Reduced bending of the membrane

1. INTRODUCTION

MEMS (Micro Electro Mechanical systems) switch for radiofrequency and microwave applications has been the main subject of elaborate research in recent years. Depending on the design, RF-MEMS switches can operate at frequencies from 0.1 GHz up to 60 GHz and can be actuated through four types of forces electrostatic, magnetic, piezoelectric or thermally produced forces, to bring about a short circuit or open circuit in the CPW transmission line carrying the RF signal. Most of the RF-MEMS switch designs use the electrostatic actuation due to its very low power consumption, electrode size, thin layers of materials, and fast switching times. In this type of switch, an electrostatic force is produced between an electrode on the substrate and the movable microstructure membrane suspended above it, inducing the movement of the membrane.

The need to produce these kinds of micromechanical switches is to improve the performance of the devices in the switching front as in the traditional IC switches there is a lot of energy loss and they are easily affected by the nearby circuit if it works at higher frequencies. The main objective for this design approach for switches has been the ease at which the electrical properties of the switch can be changed as per the requirement of the application by increasing the isolation and reducing the insertion loss. Then comes the power consumption which is also reduced very much and the actuation voltage to make the electrode attract the overlying membrane is in the range of below 5 volts.

There are three main types of RF-MEMS switches developed these days and they are cantilever, membrane, and seesaw types. In these switches one or more elastic elements are used to restore the moving part to its rest position when the actuation force is removed. In more recent research in this area these basic designs and the development of applications based on RF-MEMS switches have been done, such as tunable-filters, phase-shifters, switching networks, and antenna-arrays, rather than on the development of new RF-MEMS switch designs.

There are a number of advantages that should be considered for the wide adoption of RF-MEMS switch technology. These include high reliability, low actuation voltage, low transition time, high power handling capability. Thus, commercial applications today can employ RF MEMS switches instead of semiconductor RF switch technology.

This paper describes the design, simulation and manufacturing steps of a novel dual supply switching RF-MEMS seesaw-type switch. It is shown that, by eliminating the dependence of the dynamic movement of the RF-MEMS switch on elastic recovery forces, it is possible to reduce the transition time and the actuation voltage, and to increase the power handling capabilities.

2. PROPOSED MODEL

2.1 Design

The design shows the proposed RF MEMS switch where the coplanar wave guide (CPW) lines are formed for the RF signal pass, and electrodes on both sides for the membrane operation on the silicon substrate. The signal line width of the CPW line is 40µm and the gap between the metal contact and the broken CPW line is 4µm, initially. The gap of the broken signal lines is 15µm. The membrane, with pivot and folded springs for membrane actuation, is formed on the silicon wafer. A pivot is formed under the centre of the membrane which is used for the seesaw mode operation when the membrane is actuated downward. The fixed part is composed of four main components: the CPW transmission lines; pull-up electrodes; the switch main tower; the tower placer structure manufactured on top of the tower structure, which encloses and defines the position of the seesaw movable part and constrains its movement to the desired axis of rotation. All these components are built on a quartz wafer. Since the movable part is physically detached from the switch main body. A second quartz wafer is used to manufacture the seesaw movable part. Initially, the switch is in the “off” state and the gap between the bottom electrode and membrane is 4µm.

When the DC voltage is applied to the pull-down electrode, the membrane is actuated downward. The contact pad metal connects the broken CPW line and the switching changes to the “on” state. The electrode and membrane have no gap when the switch is in the “on” state.

Because of the 30µm thickness membrane and the pivot, no gap is left to get maximum insertion properties with very less loss without bending and making it possible to operate the switch at a very low voltage. When the DC voltage is applied to the other pull-down electrode, this membrane operates like a seesaw and the switching changes to the other signal line to the “on” state. As long as the DC voltage is applied to the driving electrode or restoring electrode, the switch operates in this seesaw-like mode. The estimation of the actuation voltage with an applied bias has been simulated using the simulation tool COMSOL Multiphysics. When a DC bias in the range of 5V-10V is applied between the pull-down electrode and the silicon body, it is observed that the contact pad moves downwards by 1.5 µm.

2.2 Fabrication and Measurement

The membrane with the pivot is to be on a silicon wafer and the CPW line is fabricated on the cavity of a glass wafer. An anodic bonding method has been used to assemble these two wafers. On the Si wafer, 500 nm of thermal oxide is deposited to form an insulation layer, and patterned by a wet etch method. To fabricate the contact metal, an Au layer is deposited and patterned by a wet etch method. Poly-Si is deposited on this glass wafer by using low pressure chemical vapor deposition (LPCVD) equipment. This poly-Si layer is used for the glass etching mask. The Poly-Si is patterned by using a reactive ion etcher (RIE), and then a cavity of glass is formed by using a buffered oxide etchant (BOE). After the glass etching process, the poly-Si layer is stripped by using a tetra methyl ammonium hydroxide (TMAH) solution and Au is sputtered on the glass wafer and patterned using Photoresist.

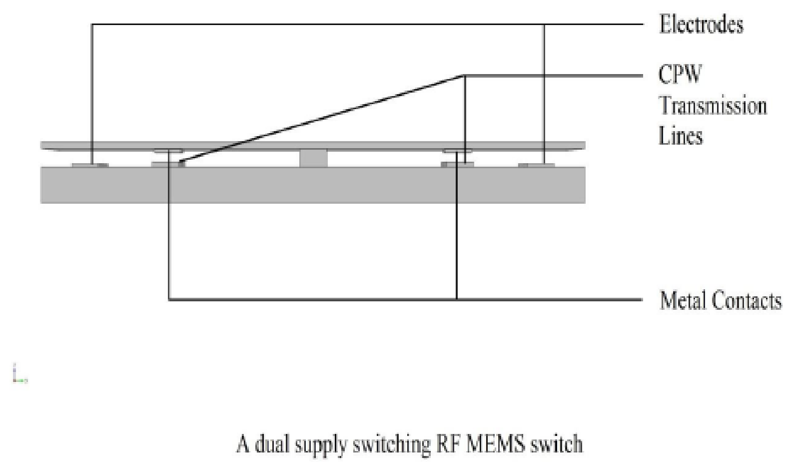

Figure 1: A dual supply switching RF MEMS switch designed in COMSOL Multiphysics

The Au CPW line and the electrode pattern are defined by using an Au wet etching process. After completion of the processing of each of the wafers, the initial cleaning is carried out for the bonding. The Si and glass wafer are bonded by using an anodic bonding method.

3. RESULTS AND DISCUSSION

The bending range of the membrane has been measured by using a simulation tool COMSOL Multiphysics and a simulated output image is shown in figure 2, where the color variation denotes the height variation, the measurement unit in this figure is pascal(Pa) which shows the amount of stress undergone by the membrane.

The bending range height is within 0.2µm. The minimum actuation voltage is approximately 5V. The pivot under the membrane and the narrow gap between the electrode and the flat membrane is a critical factor in achieving the low actuation voltage and a good RF performance.

In the proposed switch the distribution of the electric potential over the moveable membrane is measured in the simulation software to get a glimpse of the electric potential at different points on the surface of the membrane.

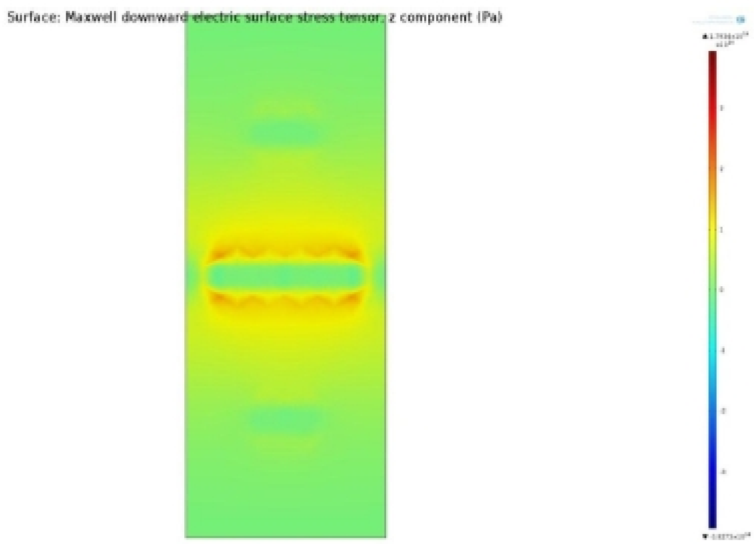

Figure 2: Downward surface stress undergone by the membrane

This electric potential distribution shows the working of the switch as to how the electrostatic actuation takes place. This measurement is shown in the figure 3. Efforts to reduce the operation voltages of the switches by optimizing the geometry design also have benefits in terms of the resulting reliability. Switches that can operate with lower voltages reduced the risk of charge accumulation because the electric fields across the membrane are lower, leading to reduced sticking effect of the membrane.

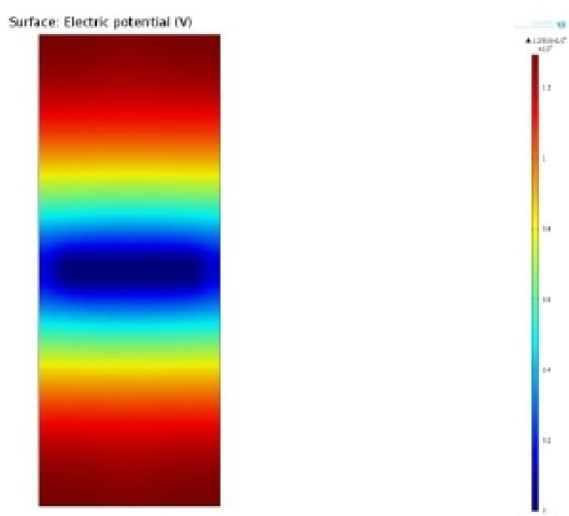

Figure 3: Surface electric potential distribution on the membrane

This new proposed design of RF MEMS switch also does not have to move a lot since the CPW lines are nearer to the pivot, reducing any internal stresses caused by the motion of the switch.

4. CONCLUSIONS

The design and characterization of a low voltage actuated RF MEMS switch for RF front end applications have been presented. A low operation voltage has been achieved by means of designing a very small gap between the electrodes and the membrane, using a flat silicon membrane and pivot with a seesaw mode of operation. The proposed switch shows very high isolation and power handling capacity. The stiff silicon also reduces the bending of the membrane, and increases the reliability of the new switch. The measured stress on the membrane due to the bending is greatly reduced here with sacrifice of the isolation properties as the metal contact is nearer to the broken signal line unlike in other seesaw type switches. But this design helps in eliminating the bending of the membrane permanently and leads to infinite lifetime with a high power coupling capacity due to the metal contact with a minimum insertion loss. The gap between the electrodes and the membrane is controlled by the depth of the etched glass wafer. In this switch the signal lines are kept closer to the pivot arrangement and so the bending of the membrane due to the electrostatic actuation is greatly reduced in this design.

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