A NOVEL CAPACITIVE RF MEMS SWITCH WITH A SILICON/METAL/DIELECTRIC MEMBRANE

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ABSTRACT

In this paper, a novel capacitive RF MEMS switch with a silicon/metal/dielectric as a membrane fabricated on anodically glass substrate bond is presented. Based on micromachining technology, fabrication processing for the switch is described. With dielectric apart from transmission line, the lower insert loss can be realized for our switch. The simulation model of this switch is developed and the analytic results are given out. According to those results, the geometry of the structure can be optimized if the beam material, threshold-voltage and the resonate-frequency are given.

KEYWORDS

Capacitive, RF, MEMS, Switch, Membrane, Micromachining

1. INSTRUCTION

RF switches are widely applied in wireless communication systems, such as phase shifters, receiver and transmitters. MEMS technology has made it possible to develop micromechanical switches with high performance for switching microwave signals. Recently, there have been many research works on micromechanical microwave switches [1]-[4]. Compared to conventional electromechanical switches, the micromachined ones have many advantages such as small size, low power dissipation, high throughput, integration capability and so on. Meanwhile, comparing to solid-state switches, they have higher breakdown voltage, lower insertion loss, and much higher off-state resistance.

The capacitive RF MEMS switches are mainly composed of three parts: CPW, dielectric layer, and membrane, and they are mostly actuated electrostatically. In most of reports, the dielectric is silicon nitride or dioxide deposited on the transmission line. In all the papers that we can reach, the membrane is made of metal deposited by electroplating process. Capacitive RF MEMS switches have relative high actuation voltage and low isolation.

In this paper, a novel capacitive RF MEMS switch with silicon as membrane and glass as the substrate material fabricated by bonding process is presented. The mechanical properties of the silicon membrane are better than that of the metal so that it can work in high stability and high reliability. In addition, its switching time could be shorter, and lifetime could be longer.

2. STRUCTURES AND PROCESS

Fig.1 is the schematic of the structure of our capacitive RF MEMS switch.

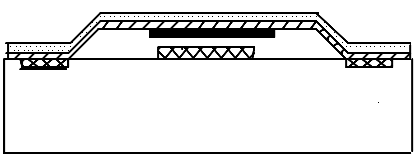


Fig. 1 schematic of the structure

The membrane of the switch consists of three layers: silicon/metal/dielectric. A dielectric layer is deposited not directly on transmission line like all of other researchers but the surface of membrane opposite to the transmission. It is in such structure that a RF MEMS switch with extremely low resistive loss or insertion loss could be designed and fabricated. When a DC voltage is applied between the upper and lower electrodes, the thin membrane deflects downward due to the electrostatic attraction between the electrodes. As the applied voltage surpasses the pull-in voltage of the switch, the membrane deflection range reaches the substrate, thus effecting a through path.

The brief fabrication sequence for the RF

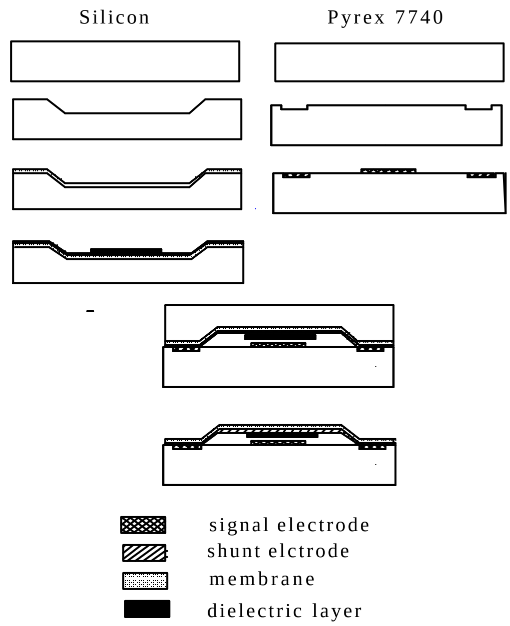


Fig. 2 Process flow

MEMS switch is shown in Fig.2.

The structure of the RF MEMS switch start with a 400μm thick high resistivity silicon wafer (ε_r=11.9) and a Pyrex 7740 glass wafer. Shallow trenches (about 2μm which is decided by the gap size) are etched on silicon by either RIE or chemically etching, followed by a heavily surface doping in order to form an etching-stop layer to determine the thickness of the membrane. A Ti/Au/Pt layer is sputtered and defined via a liftoff process with a thin dielectric film (about 2000 Å) deposited and patterned on it. The metal for transmission and ground lines are deposited and patterned on Pyrex 7740 after shallow trenches etched by RIE. The silicon wafer and Pyrex 7740 wafer are anodically bonded together face to face. The silicon wafer is wet etched from back in EDP solution, and the etch stops at heavily doped layer, then membrane topologies are patterned by ICP.

3. MODEL AND ANALYSIS RESULT

The simplified diagram of our capacitive RF MEMS switch is shown in Fig.3.

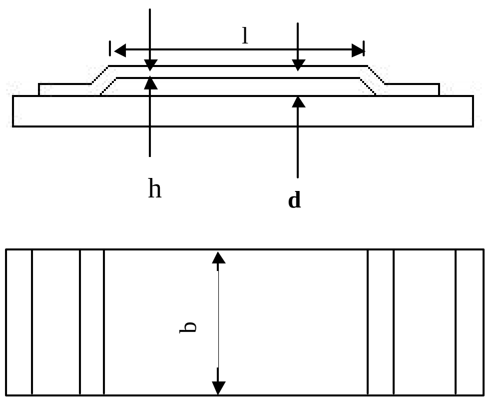
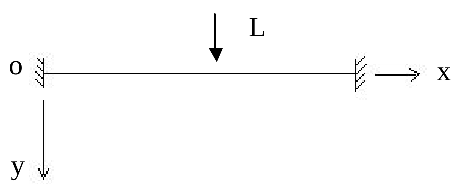


Fig.3 the simplified diagram of switch

Fig.4 Analytic model

It can be modeled as a clamped-clamped beam with the normalized load L at the middle point in Y direction shown in Fig.4. For the electrostatically actuated



clamped-clamped beam and the load is electrostatic force, the normalized load can be described as:

$$L = 4\Delta^2\left[\frac{6}{(1-\sqrt{\Delta})(1+\sqrt{\Delta})} - \frac{3}{\sqrt{\Delta}}\ln\left(\frac{1+\sqrt{\Delta}}{1-\sqrt{\Delta}}\right) - \frac{4}{1-\Delta} - \frac{4\ln(1-\Delta)}{\Delta}\right]^{-1} \quad (1)$$

$$L = \frac{b\varepsilon l^4 V^2}{384\, E_{eff}\, I d^3} \quad (2)$$

Where L is the normalized load, Δ=y/d is the normalized deflection (y is the deflection of the beam and d is the distance between the beam and the substrate), V electrostatic voltage, ε is dielectric constant of atmosphere, E_{eff} and I are the effective Yong's modulus and moment inertia of beam, and b, l and h are the width, thickness and length of beam respectively. For the beam is mainly composed of Si and Au, E_{eff} can be exhibited as:

$$\begin{aligned} E_{eff} &= \frac{(EI)_{eff}}{I_{eff}} = \frac{12(EI)_{eff}}{b_B(h_B+h_M)^3} \\ &= \frac{h_B^3}{(h_B+h_M)^3}\frac{h_M E_B E_M}{h_M E_M + h_B E_B}K' \\ &= \frac{h_B^3}{(h_B+h_M)^3}\frac{h_M E_B E_M}{h_M E_M + h_B E_B} \\ &\quad \left(4+6\left(\frac{h_M}{h_B}\right)+\left(\frac{E_B}{E_M}\right)\left(\frac{h_B}{h_M}\right)+4\left(\frac{h_M}{h_B}\right)^2+\left(\frac{E_M}{E_B}\right)\left(\frac{h_M}{h_B}\right)^3\right) \end{aligned}$$

(3)

Where E_{Si} and E_{Au} are the Yong's modulus of Si and Au and h_{Si} and h_{Au} are the thickness of Si and Au. Because both of E_{Au} and h_{Au} are about one scale less than E_{Si} and h_{Si}, so we have:

$$E_{eff} \approx E_{Si}$$

Also we can obtain the resonate frequency of the beam as followings:

$$\omega = \frac{22.45}{l^2}\sqrt{\frac{gEI}{\nu A}} = 22.45\sqrt{\frac{gEI}{\nu l^4 A}} = 22.45\sqrt{\frac{gEh^3}{12\nu l^5}} \qquad (4)$$

Where g is gravitation, ν is Poisson's ratio and A is the area of beam surface.

Equ. (1) shows the relationship between the normalized load and the deflection of the beam in Y direction. The relationship is shown in Fig.5, where threshold normalized load or threshold deflection can be obtained. When L up to L^T or beam down to

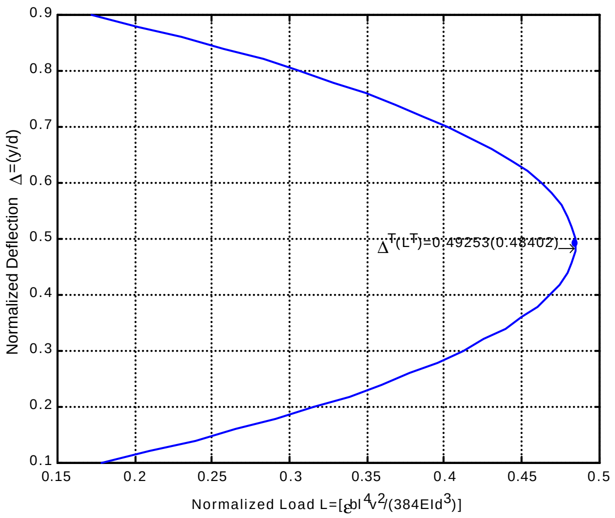


Fig. 5 the curve of L and Δ

$y^T = d\times\Delta^T$, the beam will go down to substrate abruptly. Equ. (2) is the true expression of nomalized load. Combining Equ. (2) and L^T, we can obtain the relation of threshold voltage and the mechanical properties and sizes of beam as following:

$$V^T = \sqrt{\frac{384E_{eff}Id^3L^T}{b\varepsilon l^4}}$$

Thus if the threshold voltage is given, the geometry of the structure, d, b, l, can be optimized.

CONCLUSION

A novel capacitive RF MEMS switch with a silicon/metal/dielectric as a membrane fabricated on anodically glass substrate bond is studied. As the dielectric layer is deposited on the surface of membrane instead of on transmission line, the switch with extremely low resistive loss or insertion loss could be designed and fabricated.

The simulation results show that the geometry of the structure can be optimized if the beam material, threshold-voltage and the resonate-frequency are given.

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