Abstract: In this paper, a novel method for analyzing the switching time of the electrostatic driven RF MEMS capacitive switches is presented. The effects of the structure parameters which mainly include the width, length and thickness and stress for capacitive switches MEMS bridge on time response are investigated using the SYNPLE module of IntelliSuite™ tool. The result shows that the width of MEMS bridge and the stress in bridge indistinctively affect on time response, while the length and thickness of MEME bridge distinctively effect on time response.

1. Introduction

The emergence and rapid development of radio frequency microelectromechanical system (RF MEMS) have attracted much attention from around the world. The passive RF/microwave switches implemented with MEMS methods have been shown as a promising way to developing low-power, low-cost and miniaturized RF MEMS switches for high frequency applications, such as phase shifters for satellite-based radars, missile systems, long range radars, automotive radars, instrumentation systems, satellite communication systems and wireless communication systems[1-3]. The advantages of MEMS-based RF switches over FET or PIN diodes are near-zero power consumption, high isolation, low insertion loss, low cost, light weight and IC processes compatibility, and so on. Currently the RF MEMS capacitive switches have been fabricated in both series and shunt configurations. In the shunt configurations, the RF MEMS capacitive switches are devices that use mechanical movement of MEMS components to achieve a short circuit or an open circuit in the CPW transmission line. However, the forces required for the mechanical movement can be obtained using electrostatic, piezoelectric, or thermal designs. To date, only electrostatic-type switches have been demonstrated with high reliability and wafer-scale manufacturing techniques. It is for this reason that this paper will concentrate on electrostatic driven RF MEMS capacitive switches. But they still have shortcomings, such as high-driven voltage and relatively low speed[3].

With the extensive applications of RF MEMS capacitive switches, the sensitivity of RF MEMS capacitive switches which is the switching time is the vital importance for the distributed RF MEMS phase shifters to precisely control phased-array antennas. It is the purpose this paper to analyze effects of structure parameters and stress for the capacitive switches MEMS bridge on time response. We mainly focus on discussing the effects of the width, length and thickness of the bridge and the stress in the MEMS bridge on the switching time using the SYNPLE module of IntelliSuite™ that is an available CAD for MEMS tool.

2. Principle

2.1 Mechanical Model

In order to present a systematic method of analyzing electromechanical principles of electrostatic driven RF MEMS switches, the model problem of electrostatic switches with simple geometry is first considered. The simplest model of electrostatic switches is the fixed-fixed MEMS metal bridge membrane with effective spring constant $k$, which is constructed from a top electrode of width $w$ and thickness $t_0$ that is suspended above the signal line (bottom electrode) of the coplanar waveguide (CPW) transmission line, the simplified schematically representation of the MEMS switch is shown in Figure 1. The bottom electrode is coated with a dielectric layer of thickness $d_0$ and dielectric constant $\varepsilon_r$, and the initial height between the top electrode and the dielectric is $g_0$. The top electrode is electrically grounded and a voltage $V$ may be applied to the bottom electrode.

![Figure 1 Simplified model of MEMS switch](image)

2.2 Dynamic equations

Because the RF MEMS capacitive switches are modeled
using a simple fixed-fixed MEMS bridge, the pull-down voltage is derived from static calculation and given by:

$$V_p = \sqrt{\frac{8kg_0^3}{27\varepsilon_0 W}}$$  

(1)

where \( w \) is the width of the MEMS metal bridge membrane, \( W \) is the width of the signal line, and the effective spring constant \( k \) depends on the geometrical dimensions of the MEMS metal bridge membrane and on the Young’s modulus of the material used for a fixed-fixed bridge design with a force distributed over the center third of bridge length\( l \). \( k \) is given by:

$$k = \frac{32Et_0^3w}{l^3} + \frac{8\sigma(1-\nu)t_0w}{l}$$  

(2)

where \( E \) is the Young’s modulus, \( \nu \) is the Poisson’s ratio, \( \sigma \) is the residual stress in the fixed-fixed bridge, \( l \) and \( t_0 \) are the length and thickness of the bridge, respectively. When a voltage \( V \) may be applied to the bottom electrode, the top electrode will move to contact with the dielectric. The dynamic equation of capacitive switches is derived using the Newtonian dynamic equation of motion and given by:

$$m\frac{d^2z}{dt^2} + b\frac{dz}{dt} + kz = \frac{1}{2} \frac{\varepsilon_0 W V^2}{(g + \frac{d_0}{2} - z)^2}$$  

(3)

where \( m \) is the mass of the bridge, \( z \) is the displacement from the up-state position, and \( b \) is the damping coefficient and is dominated by the squeeze-film damping under the bridge. For two parallel plates, \( b \) is given by\[8\]:

$$b = \frac{k}{\omega_0 Q} \approx \sqrt{2\mu_{air}I\frac{W}{g_0}}$$  

(4)

where \( \omega_0 = \sqrt{\frac{k}{m}} \) is the natural resonant frequency of the switch, \( Q \) is the quality factor of MEMS bridge, and \( \mu_{air} \) is the viscosity of air \( (\approx 1.8 \times 10^{-5} \text{ kg} / \text{m}^3) \).

3. Response time analysis and discussion

It is obviously that equation (3) is a non-linear, complicated differential equation. For years, it has been investigated by many researchers using the methods of numerical analysis, and several perfect approximations are adopted to computer the switching time\[8\]. However, the effects of the width, length and thickness of the bridge and the stress in the bridge on the switching time are not accurately given in their discussions. Therefore, this paper mainly analyzes the effects of the width, length and thickness of MEMS bridge and the stress in MEMS bridge on the switching time by the SYNPLE module of IntelliSuite\textsuperscript{TM} software, the switching time of the electrostatic driven RF MEMS capacitive switches will be computed for the following input data: \( g_0 = 2.5 \text{ um} \), \( W = 100 \text{ um} \), \( d_0 = 0.3 \text{ um} \) and \( \varepsilon_r = 7.6 \). The results are shown in Figure 2 – Figure 5 for the different structure parameters and stress.

The Figure 2 shows the relations between the length of the MEMS bridge and the time response of the capacitive switches; it is observed that the switching time decreases as the length increases from Figure 2. When the length is 150\text{um} the response time is about 23\text{us}. However, the response time is about 3\text{us} and almost no change when the length increases to 200\text{um}, 250\text{um}, 300\text{um} and 400\text{um} respectively. This demonstrates that the effects of the length on time response nearly was neglected when the length increase to a certain extent. Therefore, for the high sensitive capacitive switches, the length of MEMS bridge cannot be extremely length.

![Figure 2 Time response of the different length](image)

![Figure 3 Time response of the different thickness](image)
capacitive switches, but the thickness of the MEMS bridge can not be especially low to avoid the stiction failure of capacitive switches. Consequently, the optimization of the thickness may be importance to reduce the switching time and the driven voltage. The Figure 4 shows the time response of the capacitive switches for different width at the different applied voltages, it is observed that the switching time is unvarying as the width of MEMS bridge increases at same applied voltage from Figure 4. This demonstrates no effects of the width on time response. But, for the capacitive switches, we must select proper the width so that the driven voltage can be decreased according to equation (1) and the proper capacitive ratio between the up-state and the down-state can be obtained, which will clearly improve capacitive performance.

4. Summary

The influences of the width, length, thickness and stress on time response have been analyzed using the SYNPLE module of IntelliSuite™ tool. The results show that the switching time increase as the thickness and stress increase respectively, the switching time decreases as the length increases, while the switching time almost is unvarying as the width increases at same applied voltage. Moreover, the width and the stress indistinctively affect on time response, and the length and thickness of distinctively effect on time response. These results fit very well with the experiment and theory. Therefore, the structure parameters of MEMS bridge must properly be optimized to enhance the response insensitivity and electromechanical performance of RF MEMS capacitive switches.

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References