Design of the Two-Movable Plate Type MEMS Voltage Tunable Capacitor

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ABSTRACT

In this paper, we have proposed and designed the new structure of a RF-MEMS voltage tunable capacitor, which have two-movable parallel plates using electrostatic method and can be fabricated by the MEMS technology. Capacitance of the designed voltage tunable capacitor has from 1.0pF to 1.48pF as the applied bias voltage from 0.5V to 2.52V. The effective area and the distance of the capacitor plates are 335_335μm^2 and 1μm for 1pF, respectively. And the results of the simulation by the HFSS simulation program for designed tunable capacitor will be shown by the graph. The frequency range of this simulation is from 1GHz to 7GHz. The result is shown that the magnitude of the resistance is very smaller than that of the capacitance in the designed tunable capacitor.

Keywords: Design, RF-MEMS, tunable capacitor, two-movable parallel plate, electrostatic force.

1 INTRODUCTION

In the most recent wireless communication devices as planar and non-planar antenna, duplexer, band-pass and low-pass filter, power dividers, mixer and amplifiers, MEMS (Micro-Electro Mechanical Systems) technologies are widely used and researched for high quality factor, wide tuning range, low phase noise and small chip size. High Q-factor can realize high dynamic ranges in tunable filter and low phase noise, and wide tuning range of VCO is essential for tuning the desired frequency and the compensation of the variation in process and temperature. MEMS technologies make it possible to realize not only ultra-low insertion loss and bias power consumption but also single chip package, which is impossible with standard semiconductor process [1]-[5].

The recent applications of MEMS technologies in voltage tunable capacitors are using two kinds of methods, an electrostatic method and an electro-thermal method. The electrostatic method is derived from varying the distance between 2 parallel plates, which are one movable and the other fixed plate, using the applied bias voltage to the both plates. In this case, the desired capacitance is accomplished by fast tuning and small space, but the theoretical tuning range is limited by Cmax/Cmin = 1.5/1 [2][3]. The electro-thermal method is derived from differential thermal expansions caused by differentiating the widths of beams, which are supporting movable plates. Compared with the electrostatic method, the electro-thermal method has wider tuning ranges, but it is slower and needs more space. In case of the electro-thermal actuator type is reported that the maximum tuning range is 4:1 [4][5]. We propose the new model, which has the two movable plates different to classical model, for MEMS tunable capacitor using the electrostatic forces, in this paper.

2 PRINCIPLES OF OPERATIONS

The classical capacitor structures have one movable plate type. But, the proposed structure of MEMS tunable capacitor has two movable plates, in the paper. Figure 1 shows the model of the proposed tunable capacitor.

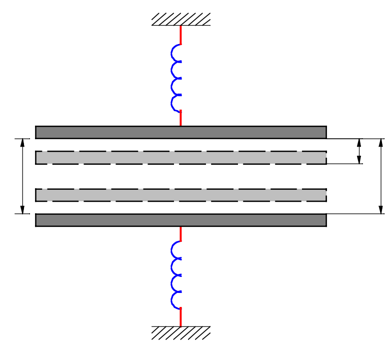


Figure 1: The model of the proposed capacitor.

When the bias voltage V_{bias} is supplied across the capacitor plates, two plates are attracted toward the opposite plate due to the resultant electrostatic force. This electrostatic force can be written as follows:

$$F_E = \frac{\varepsilon A V_{bias}{}^2}{2(d-2x)^2} \quad (1)$$

where ε is the dielectric constant of air, A is the area of the effective capacitor plate, d is the distance between the capacitor plates, and x is the moved distance by the bias voltage.

When the bias voltage is applied across plates, spring force is occurred at two suspended plates. This spring force (F_S) can be described as follows:

$$F_S = 2kx \tag{2}$$

where k is the spring constant. Constant k_t and k_b are spring constant of the top and bottom plates in the figure 1, respectively. And k is equal to k_t and k_b for the easily calibration.

Two movable plates are moving toward the opposite direction until equilibrium between the electrostatic and the spring force is reached [2]. This equilibrium between the forces can be written mathematically as follows:

$$2kx = \frac{\varepsilon A {V_{bias}}^2}{2(d-2x)^2} \tag{3}$$

The capacitance, when the bias voltage is not applied across the plates, is reference or minimum value for the voltage tunable capacitor. When the bias voltage is applied, the distance between plates, d-2x, is decreased, and then the capacitance is varied as the magnitude of the bias voltages. In this case, the distance x is calibrated by the equation 3, and the varied capacitance is obtained by the equation 4 as solving the varied distance between plates.

$$C = \frac{\varepsilon A}{(d-2x)} \tag{4}$$

3 DESIGN

3.1 Design of the plates

Figure 2 shows the designed tunable capacitor and figure 3 is shown the cross sectional and top views of the proposed structure of the MEMS voltage tunable capacitor. It consists of two movable plates, 8 beams and 4 anchors. The area A and the distance d of the capacitor are 382_382μm^2 and 1μm for 1pF capacitance at 2.52V bias voltage, respectively. And the effective area A is 335_335μm^2.

The component of the plates is poly-silicon what is doped by phosphorus. The thickness of the plate t1 and t2 are 1.6μm and 1.2μm, respectively. The nitride layer is deposited on the substrate silicon because the effective of the parasitic capacitance can be minimized and two electrodes are separated from the substrate silicon.

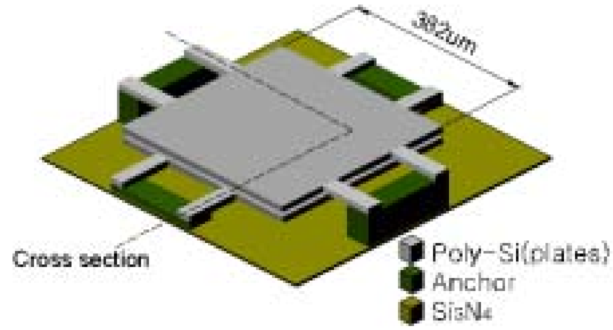
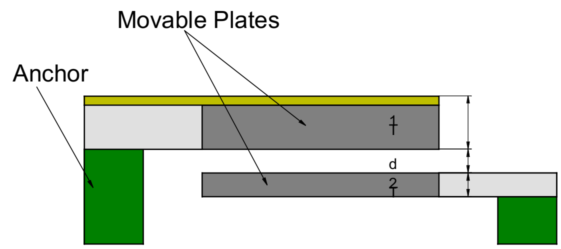
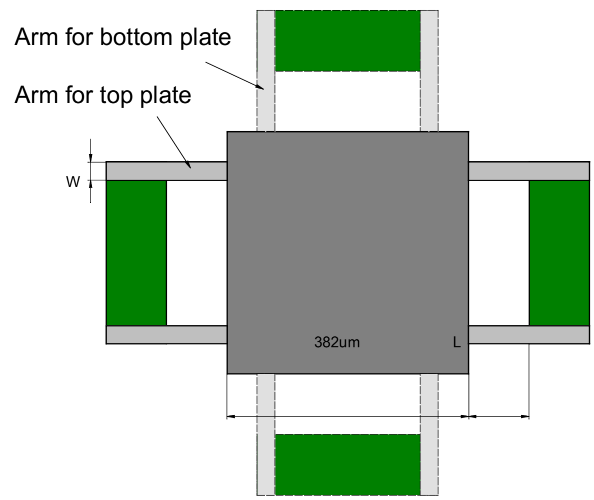


Figure 2: The designed tunable capacitor.



a) Cross-sectional view



b) Top view

Figure 3: The cross sectional and top views of the proposed tunable capacitor.

3.2 Design of the arms

Figure 4 is shown the structure of the arms what are supposed to top and bottom plates. It is related to spring constants. Spring constant is very important because it is related to the bias voltage. The spring constant can be written by

$$k = n\frac{EWT^3}{L^3} \tag{5}$$

where n is the number of the arms, E is the Young's modulus of the poly-Silicon, and W, T and L are the width, thickness and length of the arm, respectively.

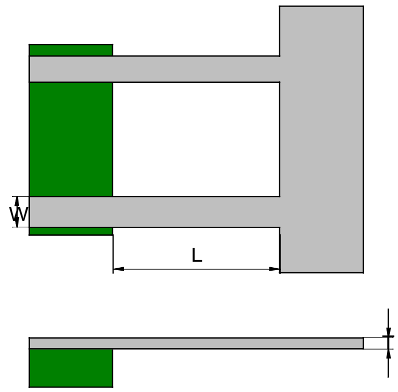
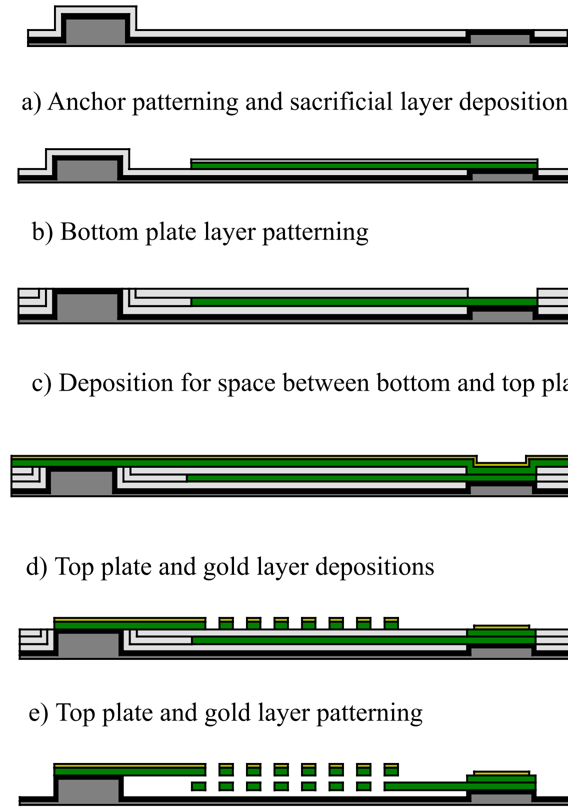


Figure 4: The structure of the arm.

The value of the spring constant is determined to 21.4[N/m] in order to achieve a maximum capacitance of 1.5pF under the maximum bias voltage of V_{bias} = 2.52V. The length, width, and thickness of the arms are 107µm, 20µm, and 1.2µm, respectively. The mass of the top plate, which is composed of the doped poly-silicon/gold layer, is 1.18µg, and the mechanical resonant frequency is 4.3kHz. The mass of the bottom plate, which is composed of the doped poly silicon layer, is total 0.3µg, and the mechanical resonant frequency is 8.5kHz.

4 FABRICATIONS

The proposed structure of the tunable capacitor has 2 movable doped poly-silicon plates, which is fabricated by the micromachining technologies. Figure 5 shows the detailed processes for the fabrication of MEMS tunable capacitor. The first, anchors are patterned by the substrate silicon etching. And nitride and sacrificial SiO_2 layer are deposited by LPCVD. Secondly, poly-silicon is deposited by LPCVD, doped by the p-type material for 10 Ω·cm and patterned by dry etching process for bottom plate. Thirdly, sacrificial layer, which is the air gap between two plates. And the fourthly, poly-silicon layer are deposited by LPCVD and gold layer is sputtered for top plate electrode. And, the next process is top plate pattering by lift-off and RIE etching. And, all sacrificial layers are released using the releasing system because of the avoidance that the top capacitor's plate is contact with bottom. Poly-silicon layers are p-type doping to 20Ω·cm for using electrode.



a) Anchor patterning and sacrificial layer deposition

b) Bottom plate layer patterning

c) Deposition for space between bottom and top plates

d) Top plate and gold layer depositions

e) Top plate and gold layer patterning

f) All sacrificial layer release

Figure 5: Processing charts for tunable capacitor.

5 SIMULATIONS

We proposed the new model, which has two movable capacitor plates. The results of the simulation for the proposed structure are shown in figure 6 and 7. Figure 6 shows the results of the simulation by the C-language program using the equation 3, 4 and 5. Varied distance 2x of the designed voltage tunable capacitor has from 0.2µm to 0.3µm as the applied bias voltage from 0.5V to 2.52V. The capacitance of the designed voltage tunable capacitor has from 1.0pF to 1.48pF as the applied bias.

Figure 7 shows the result of the simulation using the HFSS program for S_{11} parameter. This simulation is executed for believing designed structure. The frequency range of the simulation is from 1GHz to 7GHz. The result is shown that the magnitude of the resistance is very smaller than that of the capacitance in the designed tunable capacitor.

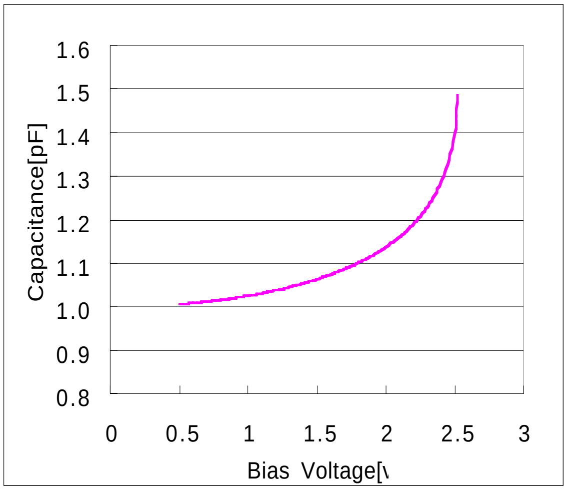


Figure 6: Result of the simulation.

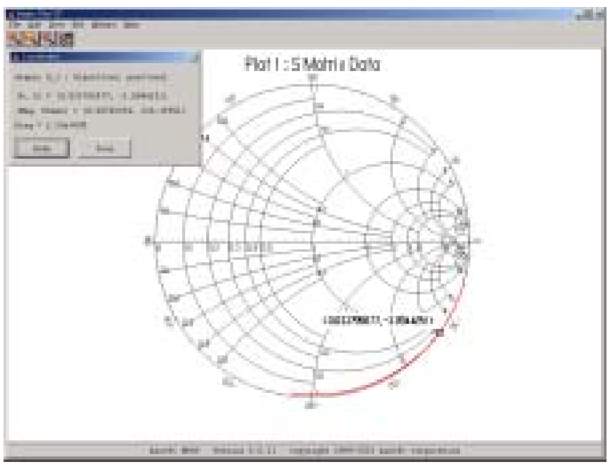


Figure 7: Simulated S_{11} parameter of the proposed tunable capacitor (simulated by the HFSS program).

6 RESULTS AND CONCLUSIONS

In this paper, the new structure, which has two movable plates, has been proposed for the RF-MEMS voltage tunable capacitor. The area and air gap of the tunable capacitor plates, which is our designed model, are 335_335μm^2 and 1μm, respectively, for 1pF capacitor. The thickness of the top plate is 1.2μm and the spring constant (k) needs 21.4N/m in order to achieve the maximum capacitance of 1.5pF under the maximum bias voltage of 2.52V. In the results of the simulation, varied capacitance has from 1pF to 1.48pF as the bias voltage from 0.5V to 2.52V. And the designed structure of the tunable capacitor can be fabricated by MEMS technologies.

It has improved the tunable range of conventional one movable plate method, and further the optimization and fabrication are expected.

ACKNOWLEDGMENTS

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