RF-MEMS Voltage Tunable Capacitor using Electrostatic Forces

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ABSTRACT

In this paper, we have proposed a fabrication method of a RF-MEMS voltage tunable capacitor using Au-electroplating technique, which has one movable parallel plate with various structure of beams. We applied an electrostatic method and electroplating technique. Electroplating technique is used to fabricate various geometric structures in the surface micromachining technology. In consequence, compared with conventional structures, the theoretical tuning range, Cmax/Cmin, can be widely ranged at the applied bias voltages.

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 650×650μm^2 and 3μm for 1pF, respectively.

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

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 are complicated to fabricate a structure of MEMS tunable capacitor has a movable plate so we have proposed a fabrication method of a RF-MEMS voltage tunable capacitor using Au electroplating, in the paper. Figure 1 shows the model of the proposed tunable capacitor.

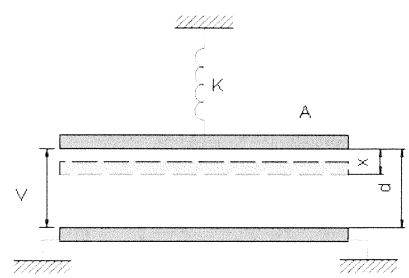


Figure 1: The model of the proposed capacitor.

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

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

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 a suspended plate. This spring force (Fs) can be described as follows:

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

where k is the spring constant. Constant k is spring constant of the top plate in the figure 1.

A movable plate is 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:

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

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-x, 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.

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

3 DESIGN

3.1 Design of the plate

Figure 2 shows the designed tunable capacitor. It consists of movable plates, beams with three kinds of length and number, and anchors. A movable plate is designed to be fabricated with Au. Figure 3 shows the simplified top and cross-section views of the proposed structure of the MEMS tunable capacitor. The area(A) and the distance(d) of the designed capacitor plate for 1pF capacitance are 650×650um^2(effective area = 593×593um^2) and 3um, respectively. The thickness of the top plate is 0.5um.

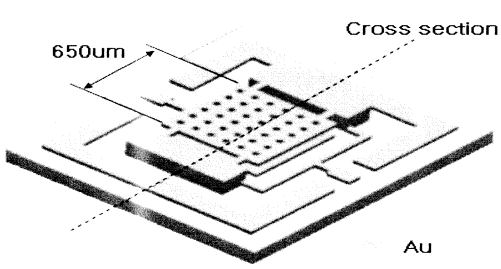
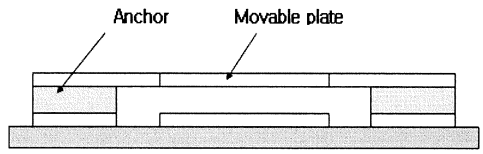
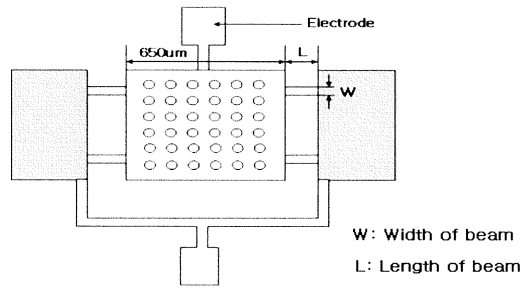


Figure 2: The designed tunable capacitor.



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 Au, and W, T and L are the width, thickness and length of the arm, respectively.

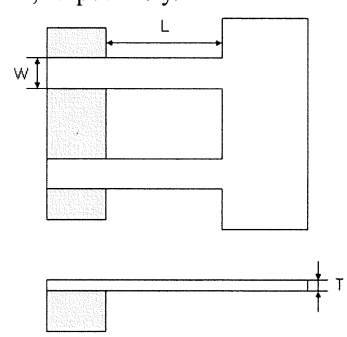


Figure 4: The structure of the arm.

The spring constants and the mechanical resonant frequency of the designed tunable capacitors are shown in figure 5. The lengths of the arms are 70μm, 80μm, and 90μm, respectively. And the width and thickness of the area are 40um and 0.5um. respectively.

	L=70um	L=80um	L=90um
2 beams	2.28	1.53	1.07
4 beams	4.57	3.06	2.15
6 beams	6.86	4.59	3.23

a) Spring constant(k), (N/m)

	L=70um	L=80um	L=90um
2 beams	0.82	0.67	0.56
4 beams	1.16	0.94	0.79
6 beams	1.42	1.16	0.97

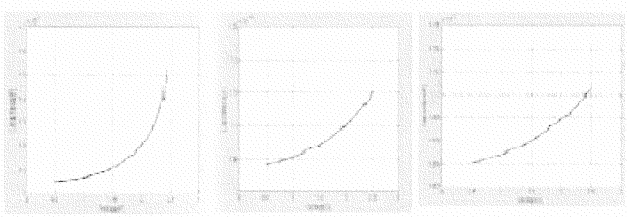
b) Mechanical resonant frequency (KHz)

Figure 5. Spring constant(k) and the mechanical resonant frequency of the designed tunable capacitor.

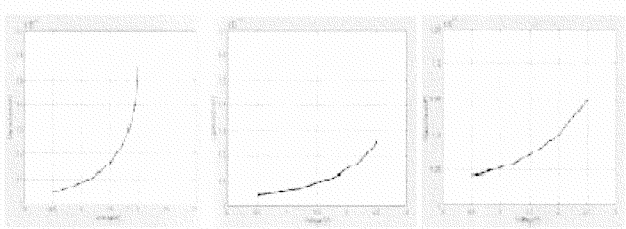
5 SIMULATIONS

We proposed the electroplating method to fabricated tunable capacitor with a movable plate. The results of the simulation for the proposed structure are shown in figure 6. Figure 6 shows the results of the simulation by the MATLAB program using the equation 3, 4 and 5. Varied distance x 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.

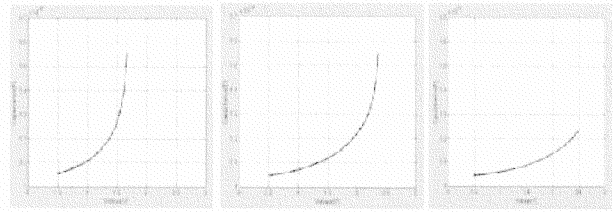
Figure 7 shows the result of the simulation using the HFSS program for S_{11} parameter. This simulation is executed for believing designed structure. The frequency range of the simulation is from 1GHz to 7GHz. The result is shown that the magnitude of the resistance is very smaller than that of the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



a) The simulated capacitance of 2, 4, 6 arms at L=70um



b) The simulated capacitance of 2, 4, 6 arms at L=80um



c) The simulated capacitance of 2, 4, 6 arms at L=90um

Figure 6: Result of the simulation.

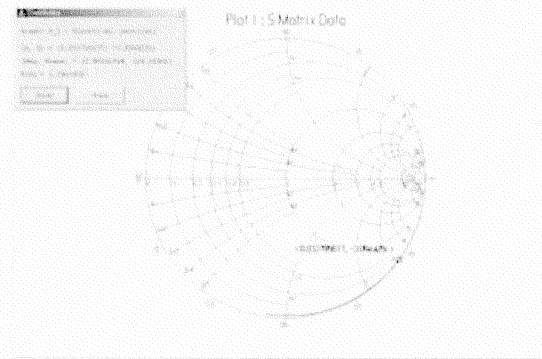
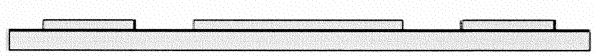


Figure 7: Simulated S_{11} parameter of the proposed tunable capacitor (simulated by the HFSS program).

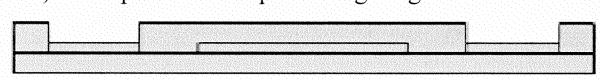
4 FABRICATIONS

The proposed structure of the tunable capacitor has a movable Au plate, which is fabricated by the electroplating. Figure 8 shows the detailed processes for the fabrication of MEMS tunable capacitor. The first, seed layer(Cr/Au) for electroplating are deposition and etching by evaporation and Au wet etching. Secondly, sacrificial Photoresist layer are coated by spin coating. And patterned areas from the seed layer are electroplated 3um for anchor to support a top plate. Thirdly, Gold layer is evaporated and etched for top plate. And, the next process is sacrificial layers removal by using acetone, PR stripper and PR ashing system, Respectively.

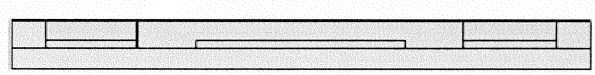
Figure 9 shows the fabricated tunable capacitors.



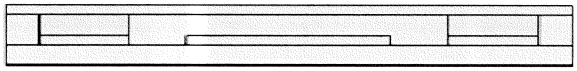
a) Au deposition and patterning on glass wafer



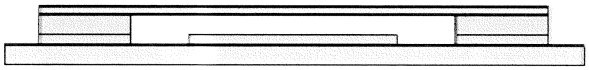
b) PR coating and parrerning



c) Au electroplating



d) Au deposition for top plate



e) PR sacrificial layer removal

Figure 8: Processing charts for tunable capacitor.

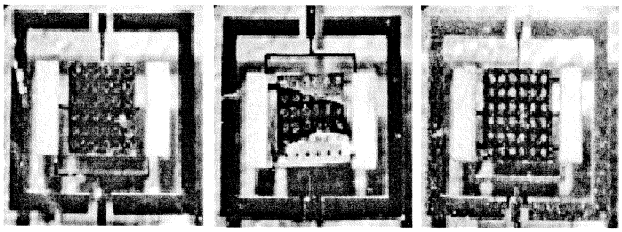


Figure 9: The fabricated tunable capacitor

6 RESULTS AND CONCLUSIONS

In this paper, the structure, which has one movable plate with various forms of beams, 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 593×593um^2 and 3um, respectively, for 1pF capacitor. The thickness of the top plate is 0.5μm. In the results of the simulation, varied capacitance has from 1pF to 1.48pF as the bias voltage from 0.5V to 2.52V.

It has improved the fabrication method for RF-MEMS tunable capacitor using an electroplating and various structures of beam, and further the optimization and measurement are expected.

ACKNOWLEDGMENTS

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