A HIGH PERFORMANCE AND ULTRA WIDE TUNED CAPACITOR USING NETTED MEMBRANE STRUCTURE FOR RECONFIGURABLE RF SYSTEMS

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ABSTRACT

This paper reports ultra-wide tuned RF micro-electro mechanical systems (MEMS) tunable capacitor using netted membrane structure for highly miniaturized and reconfigurable RF devices and systems applications. The proposed capacitor is also designed to achieve high linearity and capacitance values for commercial applications. Since the netted membrane is stuck to the dielectric layer of the bottom electrode not at once but each in turn as the actuation voltage is increased. In accordingly, it provides extremely superior linearity and wide tuning range. The fabricated RF MEMS tunable capacitor exhibited the linearity factor (LF) of 99.29 % in capacitance versus voltage (C-V) response and the capacitance tuning range of 1.78 ~ 9.15 pF at 1 GHz, respectively.

INTRODUCTION

Nowadays, RF MEMS components have shown immense popularity in the engineering industry because they have many advantages such as smaller size, better performance, and a large reduction in power consumption. In particular, MEMS tunable capacitors are the key components in intelligent and reconfigurable RF circuits and systems. They have been used for the development of tunable filters, impedance matching networks, and oscillators [1]. Among these RF MEMS tunable capacitors, the parallel plate based device using electrostatic force has been widely researched due to their geometry advantages such as simple structure, low loss, simple fabrication, and high-quality factor.

However, these parallel plate based tunable capacitors have some drawbacks such as nonlinear C-V responses, small tuning range, and low capacitance value [2, 3]. When an actuation voltage is applied between the parallel plates, they initially have low sensitivity. However, when an actuation voltage is increased, the rate of the membrane's down movement is increased dramatically and the membrane is suddenly stuck to the dielectric layer. Hence, this causes the nonlinearity of the C-V response and consequently small tuning range is happened as shown in Figure 1 [4]. There are several reports to improve the linear C-V response by using the adjusting direction of the top plate or detaching the top plate when the actuation voltage is applied [5, 6]. However, their linearity, tuning range, and capacitance values are still limited for commercial and practical RF applications. Therefore, much research efforts are still required to improve the performances of tunable capacitors.

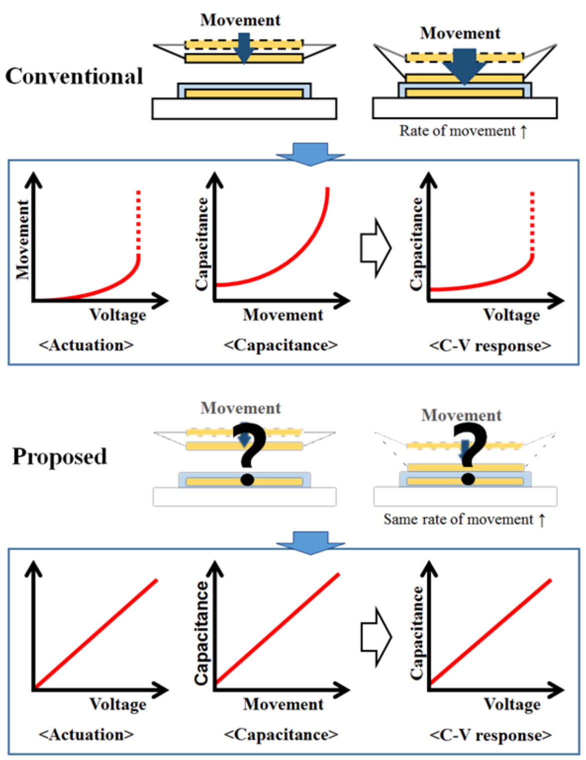


Figure 1: Schematic drawings of performance characteristics of conventional and proposed RF MEMS tunable capacitor and characteristics.

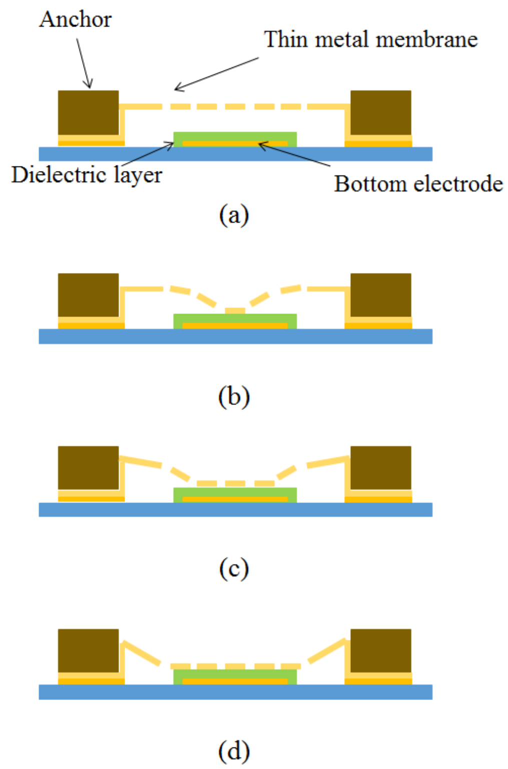
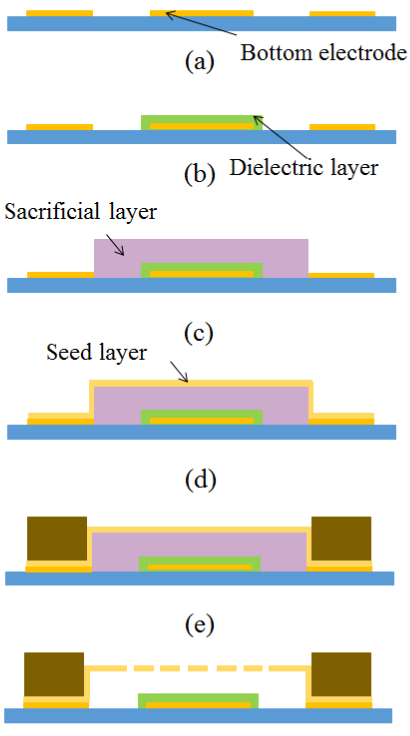


Figure 2: The operation principle of proposed RF MEMS tunable capacitor with a wide tuning range: (a) initial state, (b) center of the netted membrane structure moving down, (c) other membranes moving down in turn, and (d) moving and pull-down state



(f)

Figure 3: Fabrication process of the proposed RF MEMS tunable capacitor with netted membrane structure: (a) forming bottom electrode, (b) patterning Si_xN_y dielectric layer, (c) patterning sacrificial layer, (d) deposit seed layer, (e) electroplating the anchor, (f) patterning the netted membrane structure and removal of the sacrificial layer.

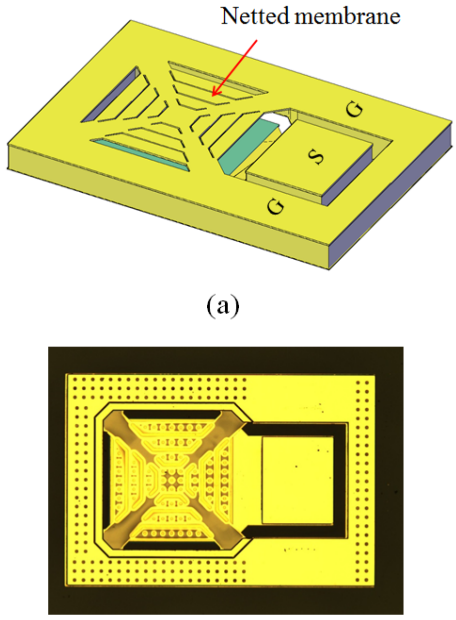
In this paper, a simple but effective geometry structure is newly proposed to get a linear C-V response and a large tuning range. The proposed netted membrane structure is newly designed to prevent a movable membrane being collapsed down onto the dielectric layer of bottom fixed electrode at once. Simultaneously, it makes each membrane stuck in turn. The proposed membrane and electrode structure are highly effective to obtain an excellent linearity C-V response and a large capacitance tuning range.

DESIGN AND OPERATION PRINCIPLE

Figure 2 shows the working principle of the proposed RF MEMS tunable capacitor with netted membrane structure. The proposed tunable capacitor is comprised of separated membrane structure which looks like net, bottom electrode and Si_xN_y layer.

Without the actuation voltage, the membrane has an initial gap of bottom electrode as shown in Figure 2 (a). When the actuation voltage is applied, then the newly designed netted membrane starts to stick to the dielectric layer in turn unlike conventional parallel plate tunable capacitors as shown in Figure 2 (b) ~ (d). The capacitance can easily be controlled by adjusting the contact area and gap distance.

The conventional parallel plate RF MEMS tunable capacitors have nonlinearity C-V response. When the pull-in phenomenon occurs, the membrane gets closer to



(b)

Figure 4 : Propsoed RF MEMS tunable capacitor: (a) schematic drawing and (b) microscopy image.

the dielectric layer. It also leads to decrease of capacitance tuning range. In contrast, proposed RF MEMS tunable capacitor creates the linear C-V response, because of the netted membrane structure. In addition, wide tuning range can be obtained due to linear C-V response.

FABRICATION

The fabrication sequence of the proposed RF MEMS tunable capacitor is shown in figure 3. First of all, coplanar waveguide (CPW) line and bottom electrode were fabricated using lift-off process as shown in Figure 3 (a). The Si_xN_y was patterned as a dielectric layer and the photo resist (PR) was spin-coated as a sacrificial layer as shown in Figure 3 (b) and (c). After that, a seed layer was sputtered to electroplate the metal and form the membrane.

Furthermore, to make anchor and CPW line, thick gold metal was electroplated as shown in Figure 3 (d), (e). Finally, the netted membrane was patterned and the sacrificial layer was released. The schematic drawing and microscopy images of fabricated RF MEMS tunable capacitor are shown in figure 4. As shown in Figure 4 (a), the proposed RF MEMS tunable capacitor has 1 port and netted membrane that worked as ground. Photograph by microscope is shown in Figure 4 (b).

The volume of the fabricated tunable capacitor is $1.0373 \times 0.7067 \times 0.089$ mm^3. The width and length of the electrostatic capacitive area are 400 µm and 400 µm, respectively.

RESULTS AND DISCUSSION

Figure 5 shows the schematic of the experimental setup. The fabricated RF MEMS tunable capacitor is measured using an Agilent E5071 network analyzer and picoprobe GSG probe with a 250 µm pitch size. RF signal and DC bias were applied together using bias tee to measure the performance characteristic of the fabricated RF MEMS tunable capacitor.

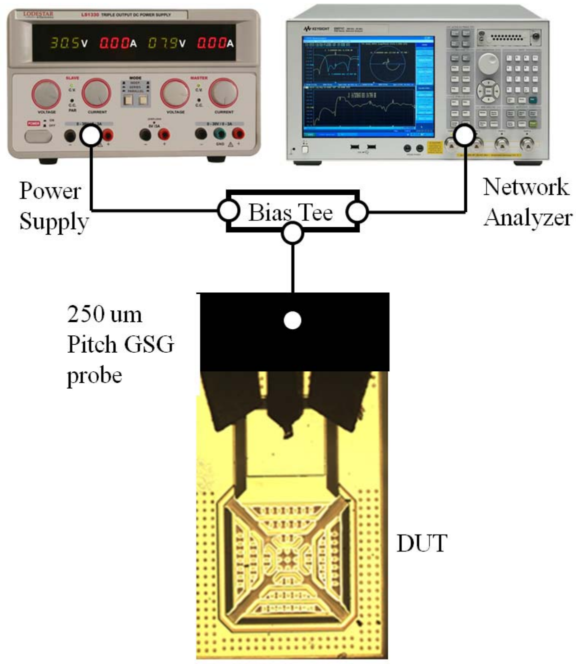


Figure 5 : Schematic of experimental test setup.

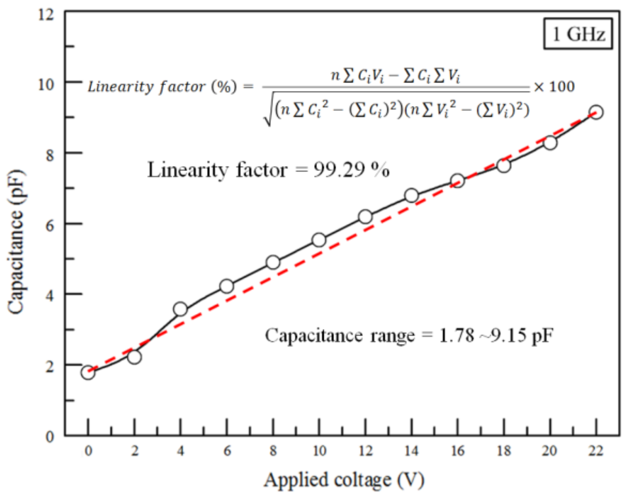


Figure 6: Measured capacitances of the capacitance-versus-voltage response of fabricated RF MEMS tunable capacitor.

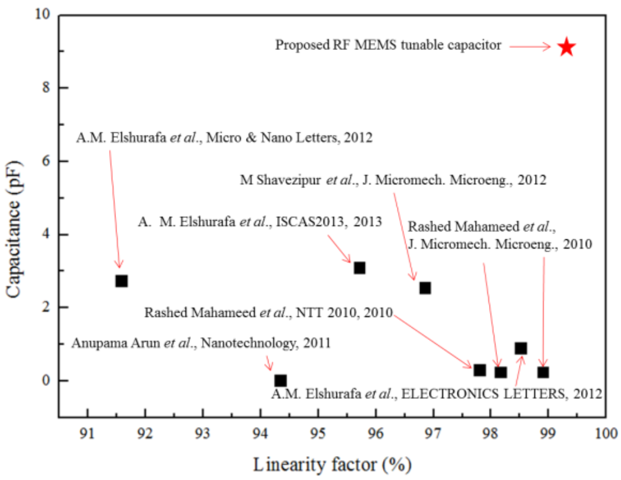


Figure 7: Comparison of proposed and previously reported RF MEMS tunable capacitors.

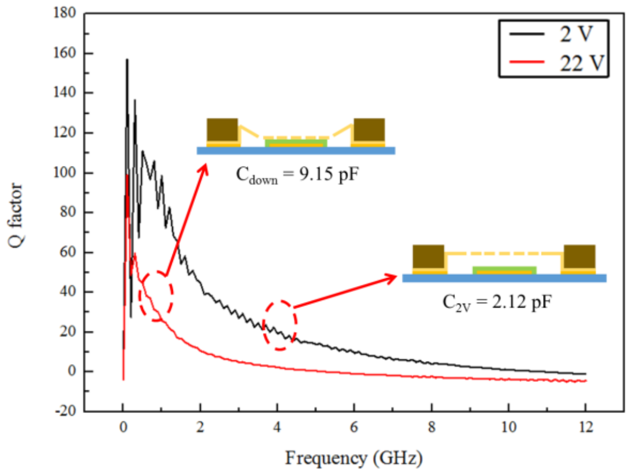


Figure 8: Quality factors of the fabricated RF MEMS tunable capacitor.

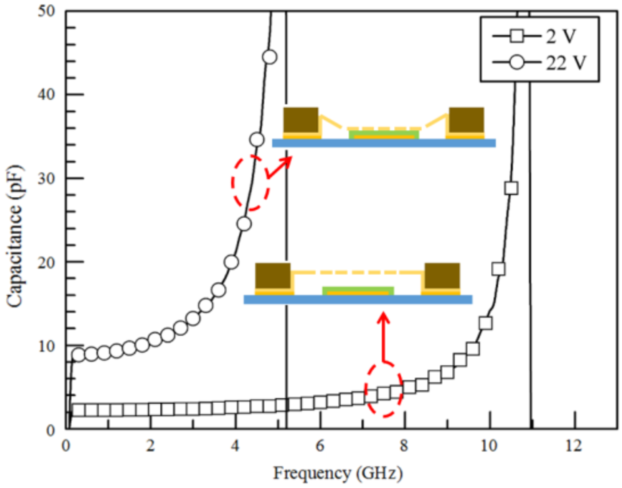


Figure 9: SRF characteristics of the fabricated RF MEMS tunable capacitor.

Figure 6 shows the C-V response at 1 GHz. The LF used in this paper was defined by the correlation coefficient equation, as described in the following [7]:

$$LF = \frac{n\sum C_iV_i - \sum C_i \sum V_i}{\sqrt{(n\sum C_i^2 - (\sum C_i)^2)(n\sum V_i^2 - (\sum V_i)^2)}} \tag{1}$$

Where, V_i is the voltage at the ith data point, C_i is the capacitance at the ith data point, and n is the number of the total data points. LF was used to define how the curve is close well to a straight line. The LF of the proposed RF MEMS tunable capacitor is 99.29 % and the capacitance tuning range is 1.78 to 9.15 pF at 1 GHz as shown in figure 6.

Figure 7 shows the comparison of proposed and previously reported RF MEMS tunable capacitors [2, 8-14]. The proposed RF MEMS tunable capacitor has excellent LF in C-V response and has wide capacitance tuning range in comparison with other RF MEMS tunable capacitors.

The measured quality factor of the fabricated device was 25.8 and 98.6 at 1 GHz, when applied DC actuation voltage was 22 V and 2 V, respectively as shown in Figure

8.

Figure 9 shows the self-resonant frequency (SRF) of 10.9 GHz and 5.2 GHz at 2 V and 22 V, respectively.

CONCLUSION

In this paper, a high performance and ultra-wide tuned RF MEMS tunable capacitor using netted membrane structure was newly designed and fabricated. The proposed capacitor was designed to achieve high linearity in C-V response by using netted membrane structure which makes those membranes stuck to dielectric layer in turn. The fabricated device exhibited excellent linearity with 99.29 % of LF in in C-V response and extremely wide capacitance tuning range of 1.78 to 9.15 pF at 1 GHz. Furthermore, the proposed membrane structure and fabrication process can be applied in various MEMS actuating devices. The developed tunable capacitors will be utilized to develop the high performance and miniaturized tunable filters and intelligent RF circuits.

ACKNOWLEDGEMENTS

This work was supported by the Technology Innovation Program (10053023, The Development of RF MEMS Devices Core Technology for Multiband IoT System Applications) funded by the Ministry of Trade, Industry and Energy (MI, Korea). The authors are grateful to the Micro/Nano Devices and Packaging Lab. (MiNDaP) group members of Kwangwoon University.

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