The Effect of Perimeter on Characteristics of Frequency−Agile Tunable Capacitors

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ABSTRACT

In this work, tunable capacitors using a finger−type electrode are designed and characterized for frequency−agile RF circuit applications. Their top electrodes with different area and line width are designed in types of the finger for a long conducting perimeter which results in enhanced fringing−electric fields in order to improve their tunability. The tunable varactors were fabricated on a quartz substrate employing a multi−layer dielectric of a para/ferro/para−electric thin film. Compared to the conventional capacitor, finger−type capacitors are characterized in terms of effective capacitance and tunablility. Their effective capacitance and tunability with the long perimeter increase 24~40% and 7~12%, respectively, due to enhanced fringing electric fields from 1 to 2.5 GHz, compared to the conventional ones.

Keyword

Tunable capacitor, ferroelectrics, paraelectrics

Ⅰ. Introduction

Frequency−agile tunable circuits have been studied for reconfigurable communications applications [1]. Several tunable passive circuits and components such as filters, matching networks, and phase shifters have been developed by using ferroelectric−based capacitors [2−5] because of its relatively high tunability, low cost, and compact size. In order to improve its performance, various materials, fabrication process, and capacitor structures have been investigated. Design rule on ratio of a perimeter to active area of the top electrode presented to reduce resistance of the electrode due to the increased current conducting perimeter [6].

In general, a fringing capacitance which is generated in parasitic has a negligible impact on the tunability [7]. In the case of inter−digital capacitors (IDCs) using mainly fringing electric fields, operation voltage depends on a spacing between electrodes and it is very high ~10 through ~100V due to the wide spacing. However, an interesting result [8] demonstrates that the fringing capacitance can be generated by using a finger−type electrode and it can contribute to improve tunability.

In this work, fringing−electric enhanced tunable capacitors using a finger−type electrode are designed and characterized for frequency−agile RF circuit applications. The electrodes of the top metal are designed in types of the finger with different area and line width. The capacitors are fabricated on a quartz substrate employing a multi−layer dielectric of a para/ferro/para−electric thin film. their effective capacitance and tunability are analyzed compared to the conventional tunable capacitors.

II. Design of the Tunble Capacitors

A metal−insulator−metal (MIM) tunable capacitor is made of 3 parts ; a bottom electrode, tunable dielectric, and top electrode. In order to enhance fringing−electric fields on purpose, compared with the rectangle−type electrode as the conventional capacitor, the top electrode is designed in the type of the finger as shown in Fig.1. The long perimeter due to the narrow width (W) and spacing (S) in the top metal can generate many fringing-electric fields. In this work, three finger-type capacitors with different area using a W and S of 2 and 3 ㎛ are designed. For the purpose of comparison, the rectangle-type capacitors with similar area and short perimeter are designed.

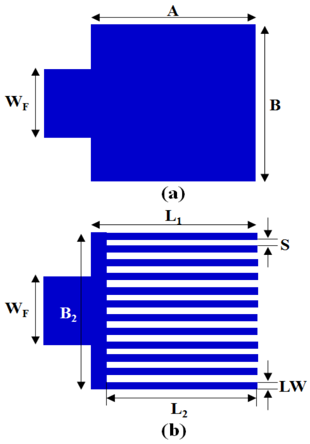

Figure 1. Layouts of the top electrode in a rectangle (a) and finger-type tunable capacitor (b).

The electrode area, dimension, and perimeter of the top metal for the finger- and rectangle-type tunable capacitors are summarized in the Table.1. By using the finger pattern, the perimeter of the finger-type capacitor is increased. For example, in the case of the electrode area with 1,192㎛^{2}, the perimeter of 119.6 ㎛ in the conventional capacitors is increased to 1,088 ㎛ in the finger-type capacitor. The multi-layer thin film of BZN/BST/BZN is used as the tunable dielectric. Its permittivity, tanδ, and tunability are 225, 0.005, and 47%, respectively.

Table. 1 Summary of electrode area, dimensions, and perimeter of the metal in the finger-and rectangle-type tunable capacitors

Top metal type	Area and Dimensions		Perimeter
	[μm^2]	[μm]	[μm]
Finger	952	LW=2, L_1=36, L_2=32, B_2=46 No. of Finger =12	848
	1,192	LW=2 L_1=46, L_2=42, B_2=46 No. of Finger =12	1,088
	1,197	LW=3 L_1=46.37, L_2=42.37, B_2=45 No. of Finger =8	755.9
Rectangle	950	A=23.75, B=40	107.5
	1,192	A=29.8, B=40	119.6
	1,200	A=30, B=40	100

III. Fabrication and Measured Results

The tunable capacitors were fabricated on the quartz substrate. The first metal (Ti/Pt=100/1,000 Å) was deposited and defined as a bottom electrode of the MIM capacitor by using lift-off process. For the multi-layer thin-film dielectric, the first bismuth zinc niobate (BZN) pyrochlore thin-film dielectrics of 700Å was deposited by RF-magnetron sputtering. The deposition was carried out from stoichiometric $Bi_2(Zn_{1/3}Nb_{2/3})_2O_7$ ceramic target in an high purity O_2/Ar mixture atmosphere. Using the Inductive Coupled Plasma (ICP) dry etcher the BZN film was patterned and then the second barium stron tium titanate (BST) thin- film of 1,500Å was deposited using a B_6S_4Ttarget and then etched. The final thin-film BZN dielectric of 700Å was deposited and patterned. The photolithography and etching process were carried out by using the same photo mask and dry etcher, respectively, for the multi-layer dielectric. After patterning of each layer, post-annealing processes were carried out at 550 ℃ for 5 minutes in air to crystallize the film. The lift-off pattern as the second metal (Cr/Au=100/1,000Å) was defined on the top of the multi-layer dielectric as the top electrode.

The effective capacitance (C_{eff}) and percentage tunability (T) of the fabricated capacitors were analyzed by measuring complex reflection coefficients (S11) with a vector network analyzer (HP8510C) and a probe-station . Using the measured S11 data, the C_{eff}, and tunability are analyzed. C_{min} and C_{max} are the measured minimum and maximum

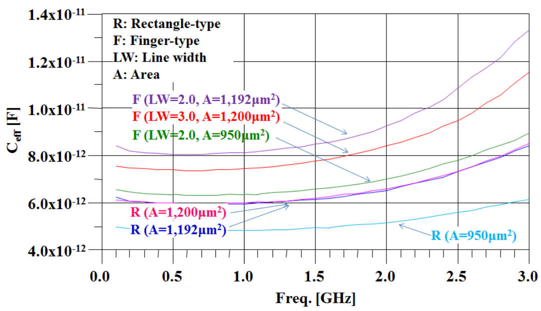

Figure 2. Measured effective capacitance (C_{eff}) characteristics of the finger-patterned capacitors with different the line widths, compared to the conventional ones. In this test, DC bias was not applied.

Fig. 2 presents measured C_{eff} characteristics of the finger-type capacitors with different the area (A) and line width (LW) of the top electrode, compared to the conventional rectangle-type capacitors. As it can be clearly seen, the finger-type capacitors with longer perimeter than that of the conventional rectangle-type capacitors show high C_{eff}. For the case of nearly same area (A=1,192 and 1,200㎛^{2}), while the conventional capacitors show the nearly same C_{eff} at each frequency. C_{eff} of the finger-type capacitors with LW=2 and 3㎛.

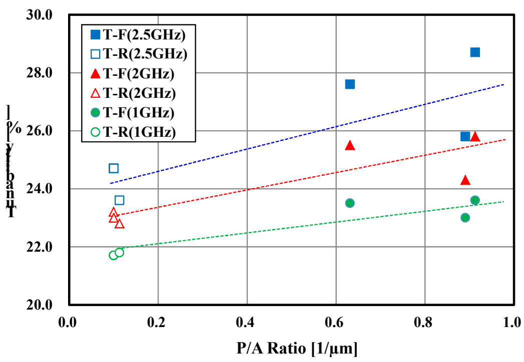

Figure 3. Comparison of the tunability and perimeter-to-area (P/A) ratio, [T-F and T-R: tunability of the finger- and rectangle-type capacitor, respectively]

Fig. 3 shows comparison of the tunability and perimeter-to-area (P/A) ratio. As the P/A ratio and frequency increase, the tunability increases. These results mean that the longer perimeter and higher frequency enhance fringing E-fields.

IV. Conclusion

This paper demonstrates fringing-electric fields enhanced by a finger-type electrode can improve the tunability of the tunable capacitor. Its top electrodes with different area and line width are designed in types of the finger for a long conducting perimeter. The tunable varactors were fabricated on a quartz substrate employing a multi-layer dielectric of a para/ferro/para- electric thin film. Compared to the conventional capacitor, finger-type capacitors are characterized in terms of effective capacitance and tunablility. Their effective capacitance and tunability with the long perimeter increase 24~40% and 7~12%, respectively, due to enhanced fringing electric fields from 1 to 2.5 GHz, compared to the conventional ones.

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