한국항행학회 논문지 제17권 제6호 2013년 12월 (JKONI 17(6): 720-725, Dec. 2013)

BZN/BST/BZN 박막에 기초한 가변 바렉터의 상부전극 가장자리 길이에 대한 가변성 영향

The Effect of Top-electrode Perimeter on the Tunability of Tunable Varactors Based on a BZN/BST/BZN Thin Film

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요 약

본 논문은 핑거 (finger) 형 전극에 의해 증강된 가장자리 전계가 가변 캐패시터의 가변성을 개선시킬 수 있음을 보여주고 있다. 가장자리가 긴 전극을 설계하기 위해 면적과 선폭이 다른 finger 형태의 전극들이 설계되었다. 가변 바렉터들은 quartz 기판위에 para/ferro/para의 가변 다층 유전체 박막을 이용하여 제작되었다. 기존의 일반적인 가변 캐패시터와 비교해서, 핑거형 캐패시터들의 유효 용량와 가변성 특성을 분석하였다. 1 ~ 2.5 GHz에서 증강된 가장자리 전계로 인해 긴 가장자리 전극으로 설계된 가변 캐패시터의 유효 용량과 가변성이 각각 24~40 % 그리고 7~12 % 증가하였다.

Abstract

This paper has presented that 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 analyzed in terms of effective capacitance and tunablility. Their effective capacitance and tunability of the varactors with the long perimeter increase 24~40 % and 7~12 %, respectively, due to enhanced fringing electric fields from 1 to 2.5 GHz.

Key words : Ferroelectric, Paraelectric, Tunable capacitor, Multi-layer dielectric

Key words : 강유전체, 상유전체, 가변커패시터, 다층 유전체

I. Introduction

Frequency-agile tunable circuits have been attracted much attention for reconfigurable communications applications [1]. Tunable capacitors are the key element in the reconfigurable RF systems. 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

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· 접수일자 : 2013년 8월 30일 · 심사(수정)일자 : 2013년 8월 30일 (수정일자 : 2013년 12월 13일) · 게재일자 : 2013년 12월 30일

http://dx.doi.org/10.12673/jkoni.2013.17.6.720

compact size. In order to improve its performance, various materials, fabrication process, and capacitor structures have been investigated. A bismuth zinc niobate (BZN) [6] and lead zinc niobate (PZN) [7] besides barium-strontium titanate (BST) have pursued for low loss, low voltage and wide bandwidth. A stacked parallel-plate capacitor has been proposed for improvement of its linearity [8]. Interesting research results on the capacitor structure, periphery of the electrode, have been published [9-11]. Design rule on ratio of a perimeter to active area of the top electrode presented in order to reduce a resistance of the electrode due to the increased conducting perimeter [9].

In general, a fringing capacitance which is generated in parasitic has a negligible impact on the tunability [10]. In the case of inter-digital capacitors (IDCs) using mainly fringing electric fields, high-DC operation voltage comes from a wide spacing between electrodes compared to thin dielectric thickness of metal-insulator-metal (MIM) capacitors. However, a different interesting result [11] was reported; the fringing capacitance which is generated by using a finger-type electrode can contribute to the effective capacitance and tunability.

In this paper, by using finger-type capacitors with different electrode area and perimeters, enhanced fringing electric fields improve tunability characteristics of the tunable capacitor. 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. Compared to the conventional tunable capacitors, the effective capacitance and tunability are analyzed.

Ⅱ. Design of the tunable capacitors

A parallel-plate tunable capacitor consists of 3 parts – a bottom electrode, tunable dielectric, and top electrode. In order to enhance the effect of the fringing-electric fields on purpose, compared with the rectangle-type electrode, the top electrode is designed in the type of the finger as shown in Fig.1. The narrow width (LW) and spacing (S) in the type of the finger of the top metal can generate many fringing-electric fields and that means long perimeter. In this work, three finger-type capacitors with different area are designed.

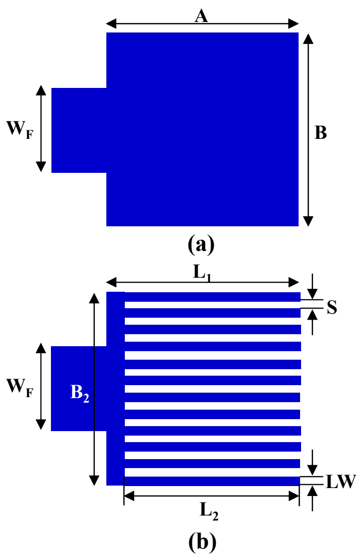

그림. 1. 사각형 (a) 그리고 핑거형 (b) 가변 커패시터에서 상부 전극의 형태

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

표 1. 사각형 그리고 핑거형 가변 커패시터의 전극 면적, 치수, 그리고 가장자리 길이 요약.

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
	[μm²]	[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

For the purpose of comparison and analysis, also the rectangle-type capacitors with similar area and short perimeter are designed. The electrode area, dimension, and perimeter of the top metal in 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 μm2, the perimeter of 119.6 μm in the conventional capacitors is increased to 1,088 μm 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.

Ⅲ. Fabrication

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. For the multi-layer thin-film dielectric, the first bismuth zinc niobate (BZN) thin-film dielectric of 700 Å was deposited by RF-magnetron sputtering. The deposition was carried out from stoichiometric Bi2(Zn⅓ Nb⅔)2O7 ceramic target in an high purity O2/Ar mixture atmosphere. The detailed process conditions such as chamber pressure, gas purity, and power of RF sputter were described in detail at the previous work [12]. Using the Inductive Coupled Plasma (ICP) dry etcher the BZN film was patterned and then the second barium strontium titanate (BST) thin-film of 1,500 Å was deposited using a B6S4T target and then etched. The final thin-film BZN dielectric of 700 Å 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=100/1,000 Å) was defined on the top of the multi-layer dielectric as the top electrode. Fig. 2 (a) and (b) show the fabricated rectangle- and finger-type tunable capacitor.

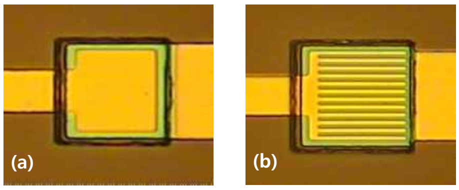

그림. 2. 제작된 사각형(a)과 핑거형(b) 가변 커패시터
Fig. 2. Fabricated rectangle (a) and finger (b)-type tunable capacitors.

Ⅳ. Measured results and analysis

The effective capacitance (Ceff) and percentage tunability (T) of the fabricated capacitors were analyzed as following equations, by measuring complex reflection coefficients (S11) with a vector network analyzer (HP8510C) and a probe station. Here, Cmin and Cmax are the measured minimum and maximum capacitance, respectively.

$$C_{eff} = -\frac{1}{2\pi \cdot freq. \cdot \mathrm{Im}(Z_{11})} \quad [F]$$

$$T = \frac{C_{\max} - C_{\min}}{C_{\max}} \quad [\%]$$

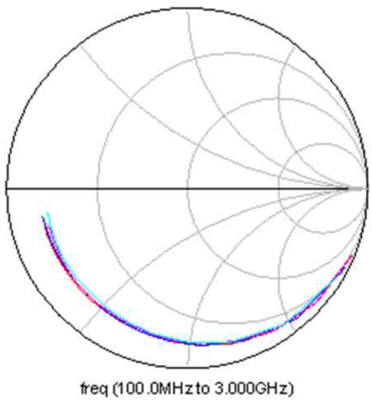

그림. 3. 제작된 커패시터의 S11 측정 특성
Fig. 3. Measured S11 characteristics on the Smith Chart of the fabricated capacitors.

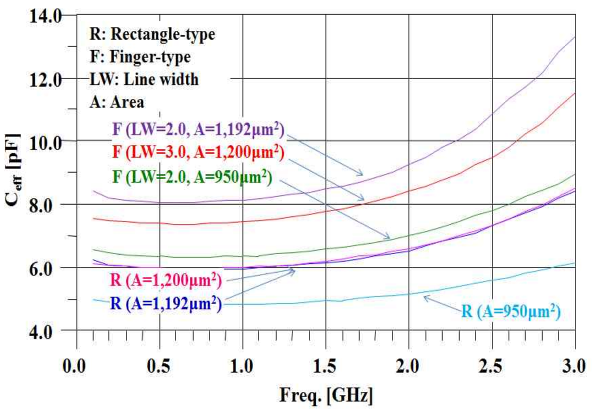

그림.4. 일반적인 사각형 가변 커패시터와 다양한 선폭변화에 대한 핑거형 가변 커패시터의 유효 용량 비교 [DC 전압이 가해지지 않음.].

Fig. 4. Measured effective capacitance (Ceff) characteristics of the finger-type capacitors with different the line widths, compared to the conventional ones. In this test, DC bias was not applied.

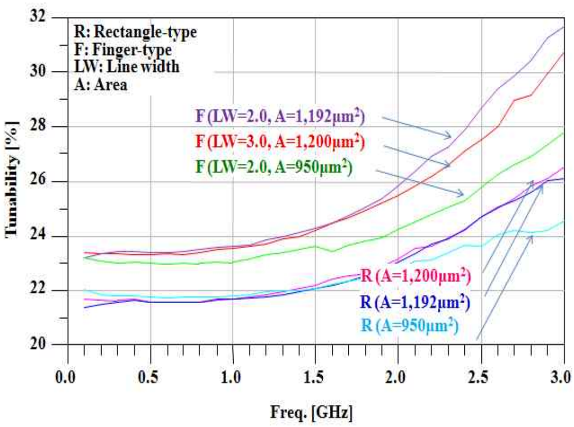

그림.5. 다양한 선폭과 면적에 대한 커패시터의 가변성 특성.

Fig. 5. Tunability characteristics of the capacitors with different electrode area and line width.

Fig. 3 shows measured S11 data on the Smith Chart of the fabricated tunable capacitors without applied DC bias from 100 MHz to 3 GHz. The self-resonant frequency (SRF) of all capacitors is over 3 GHz. The S11 traces on the Smith Chart reveal low Q-factor characteristics that result from thin metal thickness.

Fig. 4 presents measured Ceff 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 ones. As it can be clearly seen, the finger-type capacitors with longer perimeter than that of the conventional rectangle-type capacitors show high Ceff, because their fringing electric fields show effect of the longer line length and bigger area of the top electrode. For the case of the nearly same area (A=1,192 and 1,200 ㎛^{2}), while the conventional capacitors show the nearly same Ceff at each frequency. The effective capacitances (Ceff) of the finger-type capacitors with LW=2 and 3 ㎛ increase by 24 and 36 %, respectively at 1 GHz. The capacitor with the narrow LW (=2 ㎛) increases both perimeter (+45 %) and Ceff (+9.5 %), compared with that of the LW=3 ㎛ at 1 GHz. In the case of A=950 ㎛^{2}, Ceff of the finger-type capacitor increase by 32 and 45 % at 1 and 3 GHz, respectively, compared to the conventional one. Considering Fig. 4, these phenomena lead to the conclusion that the fringe E-field comes to dominate for the finger-type capacitor.

Tunability characteristics of the fabricated capacitors with different A and LW are shown in Fig. 5. The finger-type capacitors show higher tunability than the conventional ones at all measured frequencies. In particular, in the case of the finger-type capacitor with A=950 and 1,200 ㎛2, its tunability is 7~9 and 10~12

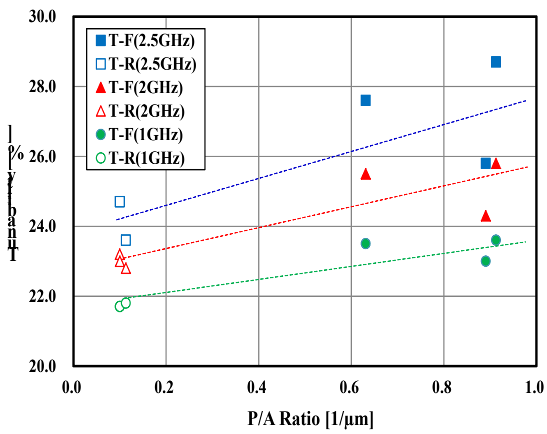

그림. 6. 가변성(Tunability)과 가장자리-대-면적 비(P/A)의 비교 [T-F와 T-R : 핑거형 및 사각형 가변커패시터의 가변성].

Fig. 6 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].

% higher than that of the conventional capacitors, respectively, from 1 to 3 GHz.

Fig. 6 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.

V. Conclusion

In this paper, we demonstrate that parallel-plate tunable capacitors with a long perimeter improve the tunability characteristics. By using finger pattern as the top electrode, the tunable capacitor with different areas and perimeters was designed and fabricated on the quartz substrate employing a multi-layer dielectric of BZN/BST/BZN thin film. The fabricated finger-type capacitors were characterized in terms of effective capacitance and tunablility, compared to the conventional one. The effective capacitance and tunability of the finger-type capacitors with a long perimeter increase 24~40% and 7~12%, respectively, due to enhanced fringing electric fields from 1 to 2.5 GHz at the same area of the top electrode. These experiments demonstrate that permittivity of the tunable dielectric in the capacitor with the long perimeter is easily changed due to fringe E-fields.

Acknowledgement

This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education, Science and Technology (No. 2011-015031).

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