Journal of the Korea Industrial Information Systems Research Vol. 19, No. 2, Apr. 2014
http://dx.doi.org/10.9723/jksiis.2014.19.2.045

Design and Fabrication of a Phase Shifter RFIC using a Tunable Multi-layer Dielectric†

이 영 철[1)]
(Young Chul Lee)

Abstract In this work, a phase shifter radio-frequency integrated chip (RFIC) using a simple all-pass network is presented. As a tuning element of the phase shifter RFIC, tunable capacitors with a multi-layer dielectric of a para-/ferro-/para-electrics using a high tunable BST ferroelectric and a low-loss BZN paraelectric thin film were utilized. In order to evaluate and analyze the fabricated phase shifter RFIC, the same elements such as an inductor and capacitor integrated into it are also fabricated and tested. The designed phase shifter RFIC was fabricated on a quartz substrate in the size of 1.16 x 1.21 mm^2. As the test results, the maximum phase difference of 350^o is obtained at 15 V and its tuning frequency bandwidth is 90 MHz from 2.72 to 2.81GHz.

Key Words : Phase shifter, paraelectric, tunable dielectric, all-pass network

1. Introduction

Recently, the multi-service requirements of the 3G, 4G, WLAN, WiFi, and several wireless communication systems [1] make several challenges such as reconfigurable function, compact size, low-current consumption, and cheap cost. In general, reconfigurable function has been implemented by tunable capacitors in the RF circuit and components.

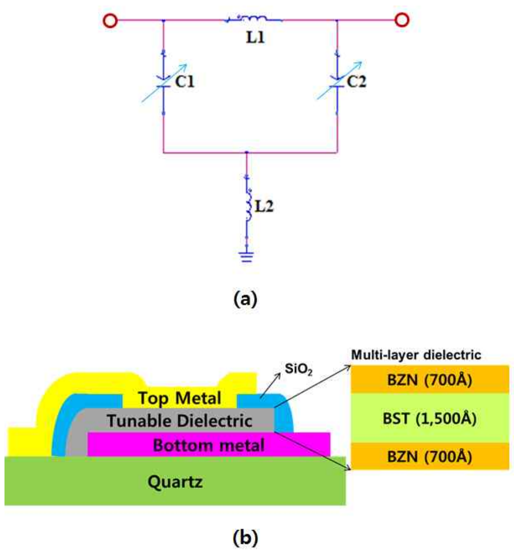
Ferroelectric- based capacitors [2-5] is one of the most promising solutions for tunable function because of its relatively high tunability, low- power consumption, low cost, and compact size. In order to improve its characteristics, several materials, fabrication processes, and capacitor structures have been developed. 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 tunability. 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].

In general, microwave phase shifter using Schottky diode and micro-electromechanical systems (MEMS) technology have been developed. However,

† 이 논문은 이 논문은 2011년 한국연구재단의 연구비 지원 의해 연구되었음(No. 2011-015031).
1) 목포해양대학교 전자공학과, 교신저자 (leeyc@mmu.ac.kr)

power dissipation and very high operation voltage are key issues to be improved. Recently, a ferroelectric barium strontium titanate (BST) thin film has been widely used for tunble RF circuit design [10-11]. A BST thin film dielectric, typical ferroelectric material, has high tunability and relatively high loss characteristics.

In this paper, a compact and low-voltage driving phase shifter RFIC using an all-pass network was designed and fabricated on a quartz substrate. In order to enhance the dielectric properties of tunable capacitors, a thin film sandwich structure of a BZN/BST/BNZ was used for low-loss and low-voltage performance of the phase shifter.



<Fig. 1> Schematic structures of a (a) all-pass network phase shifter and (b) voltage tunable capacitor

2. Design and Fabrication of a Phase Shifter

2.1 Design of the Phase Shifter

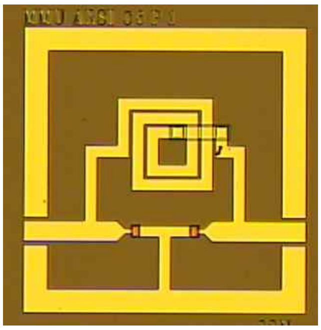
A schematic of a phase shifter using an all-pass network and a tunable capacitor are presented in <Fig. 1>. This phase shifter consists of two inductors and two parallel-plate tunable capacitors as shown in <Fig.. 1 (a)>. The capacitors are the main control elements of the phase shifter, and they are in parallel connected with the inductor. L1 and L2 is an inductance and C1 (=C2) is a capacitance which has voltage - tunable function. For 2 GHz band operation, the required values of the components are L1 = 2.2 nH, L1 = 0.2 nH, and C1 (= C2) = 3.0 pF.

In the case of L2, microstrip is used because of low-value inductance. In order to enhance electric characteristics of the tunable capacitor, multi-layer dielectric thin film of para/ferro /para-electric structure using high-tunability BST and low-loss BZN thin film as shown in <Fig. 1 (b)>.

2.2 Fabrication of the Phase Shifter

The multi-layer (BZN/BST/BZN) dielectric is utilized for low-loss and high-tunability purpose. The tunable capacitors were fabricated on a quartz substrate in coplanar waveguide (CPW) configuration. The first metal of Ti/Pt (=100/1,000 Å) was deposited and patterned as a bottom electrode of the MIM tunable capacitor by using lift-off process. For the multi-layer thin-film dielectric, the first BZN pyrochlore thin-film of 700 Å was deposited by RF-magnetron sputtering and a stoichiometric $Bi_2(Zn_{1/3}Nb_{2/3})_2O_7$ ceramic target was used in an high purity O_2/Ar mixture atmosphere. The detailed process conditions were described in detail at the previous work [3]. By using the Inductive Coupled Plasma (ICP) dry etcher, the BZN film was defined and then the second thin-film (BST) of 1,500 Å was deposited by using a B6S4T target and then etched. The final thin-film BZN dielectric of 700 Å was deposited and patterned. The photo-lithography 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 600℃ for 60 minutes in air to crystallize the film. For enhancement of capacitor's breakdown voltage and isolation between metals of the inductor, SiO_2 thin film of 3,000 Å was deposited and etched. The lift-off pattern as the second metal (Cr/Au=100Å/1,000Å) was defined on the top of the multi-layer dielectric as the top electrode. In order to evaluate and analyze the fabricated phase shifter IC, the same inductor and capacitors integrated into it were also designed and fabricated.

The fabricated phase shifter chip is shown in <Fig.. 2>. Its size is as small as 1.16 x 1.21mm^2.

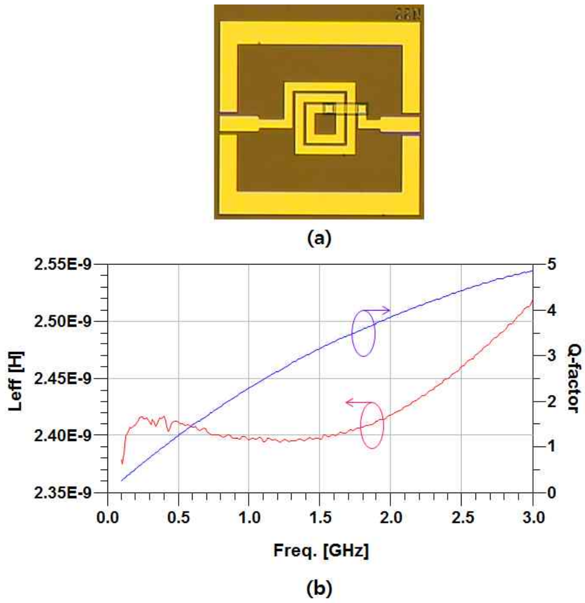


<Fig. 2> Fabricated phase shifter integrated chip (IC) [1.16 x 1.21mm^2].

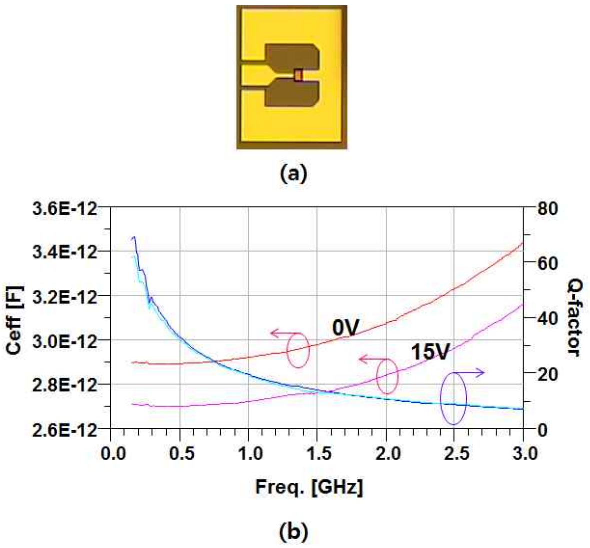
3. Measurement of the Phase Shifter

The fabricated inductor, capacitor, and phase shifter IC were analyzed by measuring complex reflection coefficients with a vector network analyzer (HP8510C) on a probe station.

<Fig.. 3> shows the fabricated inductor of 2.5 nH (a) and its analyzed effective inductance and Q-factor (b). The effective inductance and Q-factor were extracted by using measured S-parameters. At 2.0 GHz, the effective inductance of 2.4 nH and Q-factor of 3.8 were measured. Comparing to the designed value of 2.2 nH, the measured value is a little high, because of enlarged length in the test pattern and de-embedding issue. This different value of the inductor can be acceptable for the phase shifter operation.



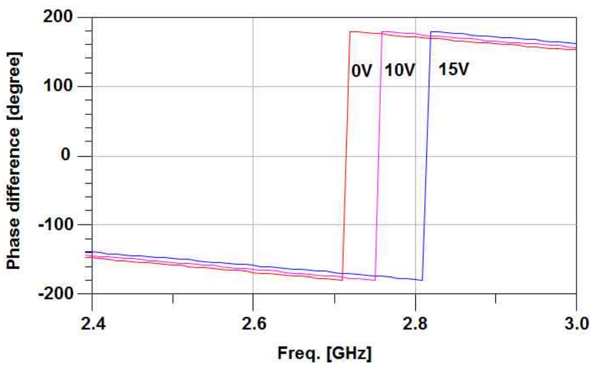
<Fig. 3> Fabricated inductor of 2.2 nH (a) and its performance (b) [Leff: an effective inductance].



<Fig. 4> Fabricated capacitor of 6.0 pF (a) and its performance (b) [Ceff: an effective capacitance].

<Fig.. 4> shows the fabricated tunable capacitor (a) and its analyzed effective capacitance and Q-factor (b). As DC voltage is applied from 0 to 15

V, the effective capacitance is tuned from 3.07 to 2.84 pF at 2.0 GHz and its tunability is 7.6 %. At the same frequency, the constant Q-factor of 10.7 is obtained in spite of applied bias.



<Fig. 5> Measured phase difference of the fabricated phase shifter IC (Fig.. 2) as the function of the difference applied DC bias.

The measured phase difference of the fabricated phase shifter to the applied DC bias voltage is shown in <Fig.. 5>. The maximum phase difference of 350 ^{o} is obtained at 15 V and its tuning frequency bandwidth is 90 MHz from 2.72 to 2.81 GHz.

4. Conclusion

In this paper, a phase shifter radio-frequency integrated chip (RFIC) based on an all-pass network has been presented. Its tuning element is a tunable capacitor based on voltage tunable dielectric thin film. For compact and low-loss tunable capacitor, the sandwich structured multi-layer dielectric thin film of a para-/ferro-/para-electrics using a high tunable BST ferroelectric and a low-loss BZN paraelectric thin film was used. The same components such as an inductor and capacitor integrated into the phase shifter RFIC were also fabricated in order to evaluate and analyze the RFIC. As the test results, the nearly same values, compared to ones designed for the phase shifter RFIC, were measured. The designed phase shifter RFIC was fabricated on a quartz substrate in the size of 1.16 x 1.21 mm^2. The maximum phase difference of 350^o is obtained at 15V and its tuning frequency bandwidth is 90 MHz from 2.72 to 2.81 GHz.

References

[1] Y Ralf Kakerow, Markus Muller, Dariusz Pienkowski, and Radu Circa, “Reconfigurable Receiver Approach for 4G Terminals and Beyond”, IEEE International New Circuits and Systems Conference (NEWCAS 2005), pp.9-12, 2005.

[2] Jiwei Lu and Susanne Stemmer, “Low-loss, tunable bismuth zinc niobate films deposited by rf magnetron sputtering” Applied Physics Letters, Vol. 83, No. 12, pp. 2411-2413, 2003.

[3] Ali Tombak, Jon-Paul Maria, Francisco T. Ayguavives, Zhang Jin, Gregory T. Stauf, Angus I. Kingon, and Amir Mortazawi, “Voltage-Controlled RF Filters Employing Thin-Film Barium-Strontium-Titanate Tunable Capacitors” IEEE Transaction on Microwave Theory and Techniques, Vol. 51, No. 2, pp. 462-467, 2003.

[4] Mossaab Ouaddari, SebastienDelprat, Francois Vidal, Mohamed Chaker, and Kew Wu, “Microwave Characterization of Ferroelectric Thin-Film Materials”, IEEE Transaction on Microwave Theory and Techniques, Vol. 53, No. 4, pp. 1390-1397, 2005.

[5] K. A. Jose, H. Yoon, K. J. Vinoy, P. Sharma, V. K. Varadan, and V. V. Varadan, “Low Voltage Tunable Capacitors for RF MEM Filters and Antenna Applications”, IEEE Antennas and Propagation Society International Symposium , Vol. 3, pp. 670-673, 2001.

[6] Ali Tombak, Francisco T. Ayguavives, Jon-Paul

Maria, Gregory T. Stauf, Angus I. Kingon, and Amir Mortazawi, "Low Voltage Tunable Barium Strontium Titanate Thin Film Capacitors for RF and Microwave Applications", IEEE MTT-S nternational Microwave Symposium, Vol. 3, pp. 1345-1348, 2000.
[7] Y. C. Lee, Y. P. Hong, D. M. Kim, and K. H. Ko, "Very high tunable inter-digital capacitor using bismuth zinc niobate thin-film dielectrics for microwave applications", Electron. Lett. Vol. 42, No.15, pp.851-853, 2006
[8] Jia-Shiang Fu, Zhu, X.A., Ding-Yuan Chen., Phillips, J.D., and Mortazawi, A., "A Linearity Improvement Technique for Thin-film Barium Strontium Titanate Capacitors" IEEE MTT-s International Microwave Symposium, pp. 560-563, 2006.
[9] Y. C. Lee and K. H. Ko, "A Tunable Capacitor Using a Finger Patterned Electrode," Microwave and Optical Technology Letters, Vol. 51, No. 2, pp. 418-421, 2009
[10] Seyit Ahmet Sis, Victor Lee, Jamie D. Phillips and Amir Mortazawi, "A DC Voltage Dependent Switchable Acoustically Coupled BAW Filter Based on BST-on-Silicon Composite Structure" IEEE MTT-s International Microwave Symposium, pp. 1-3, 2012.
[11] Albert H. Cardona, "Tunable $BaSrTiO_3$ Applications for the RF Front End" IEEE MTT-s International Microwave Symposium, pp. 1-3, 2012.

이 영 철 (Young Chul Lee)

- 정회원
- 영남대학교 전자공학과 공학학사
- 영남대학교 전자공학과 공학석사
- 한국정보통신대학교 공학부 공학박사
- 목포해양대학교 해양공과대학 전자공학과 부교수
- 관심분야 : 밀리미터파 회로 및 시스템

논 문 접 수 일 : 2014년 03월 25일
1 차 수 정 완 료 일 : 2014년 04월 16일
2 차 수 정 완 료 일 : 2014년 04월 23일
게 재 확 정 일 : 2014년 04월 23일