

TUNABLE COPLANAR WAVEGUIDE (CPW) LINE INTEGRATING BISMUTH ZINC NIOBATE (BZN) THIN FILMS

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Abstract—In this paper, a tunable coplanar waveguide (CPW) line using the bismuth zinc niobate (BZN) thin film has been proposed and demonstrated for low-voltage phase shifter applications. In order to reduce the operation bias voltage the air gaps between the signal strip and ground plane are filled with the tunable thin films. At low E-fields of 1.3 kV/cm, the fabricated CPW line shows the phase difference of 10 degree at 10 GHz.

1. INTRODUCTION

Using tunable dielectric materials such as ferro- and para-electrics, several tunable circuits have been widely applied to beam-steering antenna systems or reconfigurable RF applications because of low loss, low power consumption, and low cost, compared with other technologies as semiconductor and microelectromechanical system (MEMS) technology [1]. Therefore, various materials as $\text{Ba}_x\text{Sr}_{1-x}\text{TiO}_3$ (BST), $\text{Bi}_2(\text{Zn}_{1/3}\text{Nb}_{2/3})_2\text{O}_7$ (BZN) [2, 3], $\text{PbO-ZnO-Nb}_2\text{O}_5$ (PZN) [4], lead zirconate titanate (PZT) [5], etc. have been developed and used for design of several tunable circuits (capacitors, matching networks, filters, and phase shifters).

Especially, the phase shifter is a core element of steerable antenna systems. Recently, various researches have been carried out [6–11]. Using a delay [1, 11–13] or periodically loaded line [1, 8] CPW phase shifters have been developed and also right-handed (all-pass network) [6], left-handed [9, 10], and reflection-type [5] phase shifters using tunable capacitors have been also reported. Recently composite right/left-handed transmission metamaterials [14] have been utilized for the phase shifter applications. A 3-stage LC-ladder-type phase shifter [7] with BST thin film capacitors of the CPW line was designed. In this work a pulsed laser deposition (PLD) was used for low-loss BST deposition and at 20 and 60 V the estimated phase difference was 2.5 and 15 degrees, respectively, at 10 GHz. A periodically loaded CPW phase shifter [8] consisting of 56 same sections using BST capacitors achieved the phase difference of 170 degrees at 20 V. However its estimated total length was about 35 mm. A CPW transmission phase shifter with a matching part using BST thin films was reported [11] and its phase difference, insertion and return loss was 180 degrees, -10 dB, and -20 dB, respectively, at 150 V. A Ka-band phase shifter using an all-pass network [6] showed the insertion loss of 7 dB and phase difference of 370 degrees at 30 V. Tunable left handed transmission line phase shifters [9, 10] for compact size were developed using a thick or thin film technology. In the case of thick film phase shifter [9], it was operated at the 100 V at 2.8 GHz and its phase difference was about 73 degrees. Thin film phase shifter [10] tuned its phase of 220–270 degrees at 20 V. However, its insertion loss was over -10 dB at 10 GHz. A capacitive-loaded line [12] using another metal connected by a varactor diode with a ground plane was proposed. By applying DC bias to the varactor diode, its characteristic impedance and phase shift were changed. CPW phase shifters on the different substrates were researched. Their phase differences were less than 10 degrees at 100 V. Recently a phase shifter using MEMS switches [14] was presented. In the case of almost CPW line phase shifter, very high DC voltage (20 ~ 150 V) was required for designed phase difference and some cases showed bulky size. In the case of MEMS technology, there are some issues about high driving voltage, low switching speed, reliability, and packaging.

In this paper a tunable-dielectric-based coplanar waveguide (CPW) line has been presented for low-voltage phase shifter applications. In order to reduce electric fields at both air gaps between a signal strip and ground plane, both side gap of the CPW are filled with bismuth zinc niobate (BZN) thin films. The fabricated CPW line is characterized using a probing method.

2. DESIGN AND FABRICATION

A CPW line can be used for a phase shifter in types of a delay or periodically loaded line. By forcing external DC bias to it, the effective dielectric permittivity of the tunable thin films integrated into it is changed and its propagation constant is also varied. As a result, its phase can shift easily. Fig. 1 shows perspective view of the CPW lines. Fig. 1(a) shows the conventional CPW delay-line phase shifter [1, 11] integrating the tunable dielectrics between a substrate and metallization for the CPW signal and GND. Electric (E-) fields passing through two paths (the gaps of the CPW and the tunable dielectric thin films) change the dielectric permittivity. Therefore, very high DC bias voltage is required. In this work, the novel CPW structure for the delay-line phase shifter applications is proposed in order to reduce the DC bias voltage. In this proposed structure, the E-fields are confined around gaps filled with high-permittivity tunable dielectrics and also their pass length can be shorter than that of the conventional one. The parameters of the CPW such as the gap ($g = 75 \mu\text{m}$), width of the signal strip ($W = 70 \mu\text{m}$), and length of the line ($L = 4,000 \mu\text{m}$) were designed on a silicon substrate.

The proposed CPW line was fabricated on the silicon substrate. A 6,000 Å-thick BZN thin film was deposited on a SiO_2/Si (300 Å/500 μm) substrates by RF-magnetron sputtering as shown in Figs. 2(a) and (b). The deposition was carried out from stoichiometric $\text{Bi}_2(\text{Zn}_{1/3}\text{Nb}_{2/3})_2\text{O}_7$ ceramic target in an O_2/Ar mixture atmosphere. Using the Inductive Coupled Plasma (ICP) dry etcher the BZN film was patterned as shown in Fig. 2(c). After patterning, post-annealing processes were carried out at 700°C for 3 hours in air to crystallize the film. For the signal strip and GND planes of the CPW, the metal (Pt) layer of 6,000 Å was deposited and patterned at the etched BNZ film

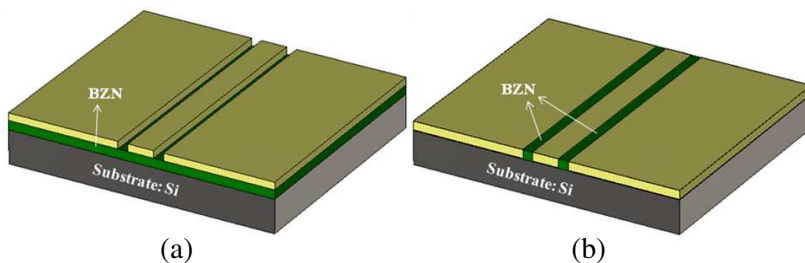


Figure 1. Coplanar waveguide (CPW) integrating tunable dielectric thin films (a) conventional and (b) proposed one.

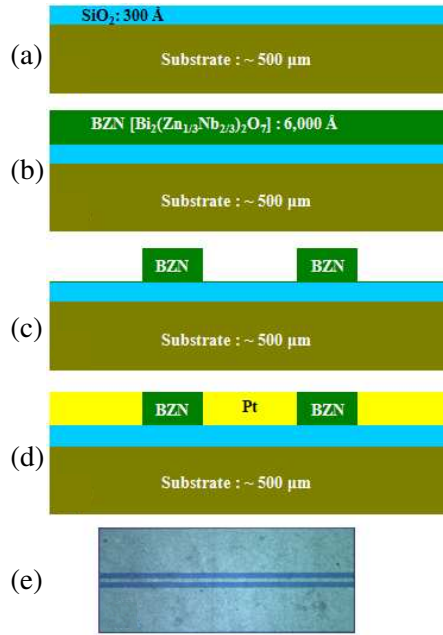


Figure 2. Process flow of the CPW line [SiO_2/Si ($300 \text{ \AA}/500 \mu\text{m}$) (a) substrate, (b) deposition and (c) etching of the BZN thin film on the silicon substrate, and (d) deposition of metal (Pt) and patterning] and (e) the fabricated CPW line.

using the sputtering and dry etching process, respectively, as shown in Fig. 2(d). The fabricated CPW line is shown in Fig. 2(e).

The performance of the BZN thin film integrated into the CPW is presented in Fig. 3. The BZN thin film was characterized by using a disk type of a metal-insulator-metal (Pt/BZN($4,000 \text{ \AA}$)/Ag) dot capacitor ($250 \mu\text{m}$ diameter). The measured relative dielectric constant and tunability are 220 and 35%, respectively, at 1 MHz.

3. MEASUREMENTS

The fabricated CPW line was investigated in the frequency range from DC to 10 GHz by measuring scattering-parameters on a probe station (Cascade Microtech, Inc). A vector network analyzer (HP 8510C) was used for characterizing the fabricated CPW. The calibration was performed using the standard short-open-load-thru (SOLT) calibration method with the calibration substrate (CS-5, GGB Industries Inc).

Figure 4 shows the measured insertion and return loss as a function of frequency at different DC bias conditions. At all DC bias conditions, measured return losses maintain less than -10 dB, although at some bias conditions (0 and 5 V) they are slightly over -10 dB. In a case of the insertion loss, at the all measured frequency range poor characteristics are observed because of the lossy silicon substrate and impedance mismatching.

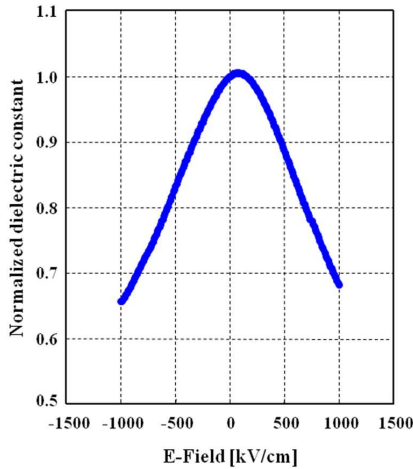


Figure 3. Normalized dielectric permittivity of the BZN thin film as a function of the DC electric field characterized at 1 MHz.

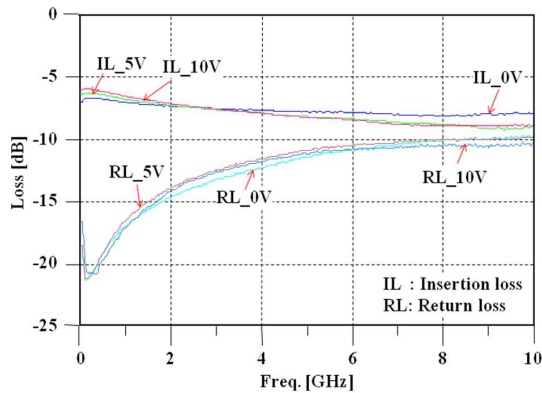


Figure 4. The measured insertion and return losses as a function of frequency at different DC bias conditions.

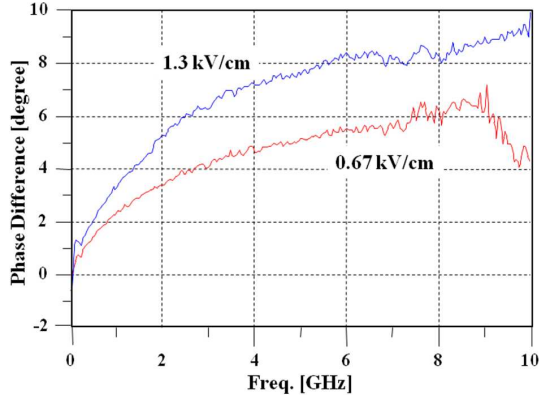


Figure 5. Measured transmission phase difference as a function of frequency at different E-fields.

Figure 5 shows measured transmission phase difference of the CPW line at different E-fields, compared with the zero bias condition. As it is seen from Fig. 5, the phase difference increases with frequency and applied E-fields. In spite of very low E-fields of 0.67 (5 V) and 1.3 kV/cm (10 V), the fabricated CPW line shows the phase difference of 5.0 and 10 degree for, respectively, at 10 GHz. Compared with previous research results about the delayed and loaded lines, the applied DC voltage of about 10 V in the proposed CPW structure is reduced.

4. CONCLUSION

A tunable coplanar waveguide (CPW) line has been proposed and demonstrated using the bismuth zinc niobate (BZN) thin film for low-voltage phase shifter applications. In order to reduce the applied bias voltage the air gaps between the signal strip and ground plane are filled with the tunable thin films (BZN). These preliminary results demonstrate that the DC bias voltage applied to the CPW line for the delay-line phase shifter applications can be reduced over 10 V, compared to previous research results.

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