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Article title: High Frequency Thick Film BST Ferroelectric Phase Shifter

Year of publication: 2004

Citation: Yeo, K.S.K. et al. (2004) "High Frequency Thick Film BST Ferroelectric Phase Shifter", *Integrated Ferroelectrics*, 61 (1) 65-70

Link to published version: <http://dx.doi.org/10.1080/10584580490458838>

DOI: 10.1080/10584580490458838

High Frequency Thick Film BST Ferroelectric Phase Shifter

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This paper discusses the performance of a thick-film ferroelectric phase shifter at high frequency. The phase shifter is fabricated from Barium Strontium Titanate (BST) thick-films on alumina substrates using a screen-printing method, and the electrodes are patterned using direct gravure-printing. We have achieved down to 40 μm gaps between electrodes using this method. Comparison between the theoretical response and experiment results will be presented. The extracted dielectric constants of the BST material using this phase shifter is also be presented here.

Keywords: Thick-films; gravure-printing; screen-printing; phase shifters

PACS: 84.40.Az; 84.40.Dc; 85.50.-n

I. INTRODUCTION

Phase shifters are important devices in communication systems. They are often used in steering phased array antenna. This paper discusses a phase shifter fabricated using screen-printed BST thick-films on alumina substrates. BST has been the most extensively investigated material because of its high tunability and low losses at room temperature. Most of the work reported to date is on BST thin-films. Although, thin-film ferroelectrics are more superior in performance, but thick-films deposition cost a fraction to manufacture compared to thin-film technology, where laser ablation and photolithographic processes are needed. Alumina is the commonly used substrate in thick-film microwave devices; however, our early study showed that the BST films are very reactive with alumina substrates when sinter above 1300°C [1]. For

BST films deposited on alumina substrates, the sintering temperatures are therefore limited to achieve the full density. The initial results show that the films, although not fully densified, have good tuneability [2], and potentially useful for tuneable applications.

To achieve tuneable ferroelectric devices with low biasing voltage, narrow conductor lines and gaps have to be realized in order to achieve the high electric field for biasing. For standard screen-printing technology, the line or gap resolution is limited to $100\ \mu\text{m}$ or above. With the recent development in the novel direct gravure-printing (DGP) method, high resolution [3] printing on thick-film can be achieved cheaply.

DGP can be performed with either a metal gravure or silicone polymer gravure. The silicone polymer gravure, which is used in this work, has two crucial advantages over the metal gravure. Firstly, the use of soft material as printing plate allows one to print on rigid substrates. Secondly, the interaction between pastes solvent and silicone polymer material helps the paste transfer [4]; a 100% transfer is possible if the printing parameters are optimised. It is possible to print narrow conductor lines and gaps down to $20\ \mu\text{m}$ in width with good edge definition using DGP with silicone polymer gravure.

II. PHASE SHIFTER DESIGN AND FABRICATION

The phase shifter presented here is a low impedance coplanar-waveguide transmission line as shown in Fig. 1. The idea of this phase shifter is to use the voltage dependant tuneability of the ferroelectric material. A low impedance transmission line is chosen because narrow gaps between the

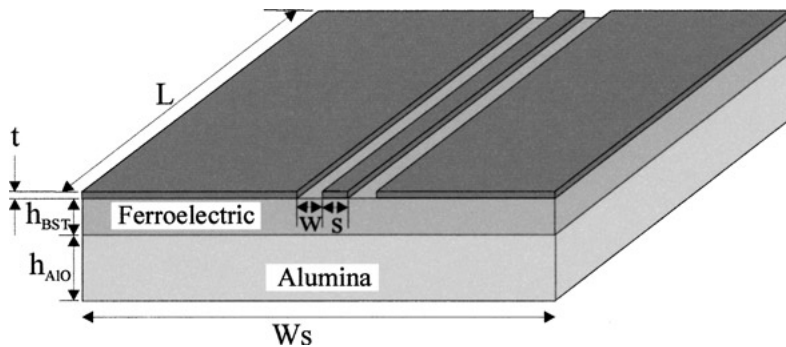


FIGURE 1 The coplanar-waveguide phase shifter layout ($L = 50\ \text{mm}$, $W_s = 10\ \text{mm}$, $h_{\text{BST}} = 30\ \text{mm}$, $h_{\text{AlO}} = 1.0\ \text{mm}$, $s = 0.18\ \text{mm}$, $w = 40\ \mu\text{m}$, $t = 15\ \mu\text{m}$).

signal line and the ground planes are needed to produce the required electric field.

The ferroelectric material used in this work is BST with a composition of $\text{Ba}_{0.6}\text{Sr}_{0.4}\text{TiO}_3$; 1-mol% Mg is added as a dopant to suppress the abnormal grain growth during sintering, and to reduce the dielectric constant and dielectric losses. BST thick-films were fabricated on 96% alumina substrates using a conventional screen-printing method and sintered at 1300°C for 2 hours. The ink was prepared by combining BST powders produced via a solid-state route together with a commercial vehicle (Blythe-6321 Medium) at a solids loading of 40 vol.%.

For electrodes, screen-printing is unsuitable because of its low lateral resolution ($\sim 100\ \mu\text{m}$). To achieve a narrow gap of $40\ \mu\text{m}$ in the coplanar-waveguide structure, DGP is used instead. In this method, the printing paste is transferred directly from the grooves of a gravure-printing plate to the substrate. First the grooves in the printing plate are treated with a paste. The substrate is then placed over the gravure and a pressure is applied. The substrate is released after the paste transfer [4] process. The printing is then performed using silicone polymer gravure. The conductor lines are printed using commercial silver thick-film paste with sintered thickness, $t = 15\ \mu\text{m}$.

III. RESULTS

The performance of the phase shifter was measured using Agilent-8722 E network analyzer. A phase shift of approximately 210° has been achieved with 90 V (approximately, 2.25 kV/mm electric field) of biasing voltage as shown in Fig. 2.

Figure 3 shows the insertion loss and return loss of the experimental and theoretical/predicted results of the phase shifter. The theoretical results are calculated using conductivity, $\sigma = 1.52\ \text{S/m}$ (conductivity of DuPont-6145 silver paste), for the signal line and ground planes and a material loss tangent of 0.01. A separate plot of the conductor loss and dielectric loss are also plotted on the same graph. The predicted responses are calculated using known loss models for coplanar-waveguide [5] in the literature combined with basic transmission line theory [6]. The loss tangent of the material is determined by fitting the theoretical insertion loss graph to the experimental graph. At higher frequencies, the experimental results deviated from the prediction because of spurious modes, which were not considered in the calculation. The spurious modes can be clearly observed in the return loss graph, where higher reflections are observed in the experimental results for frequencies above 5.0 GHz.

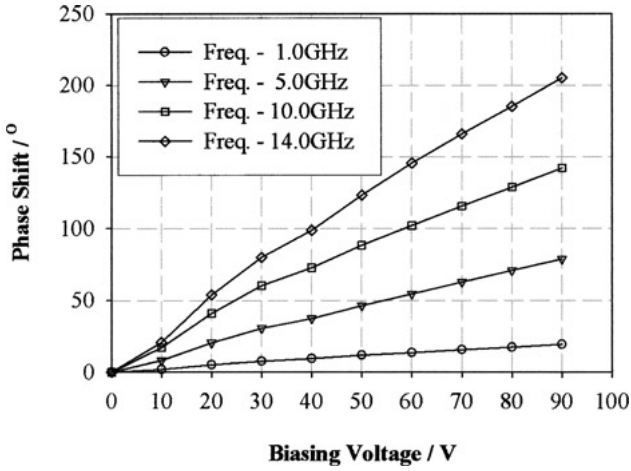


FIGURE 2 The phase shift as a function of biasing voltage at different frequencies.

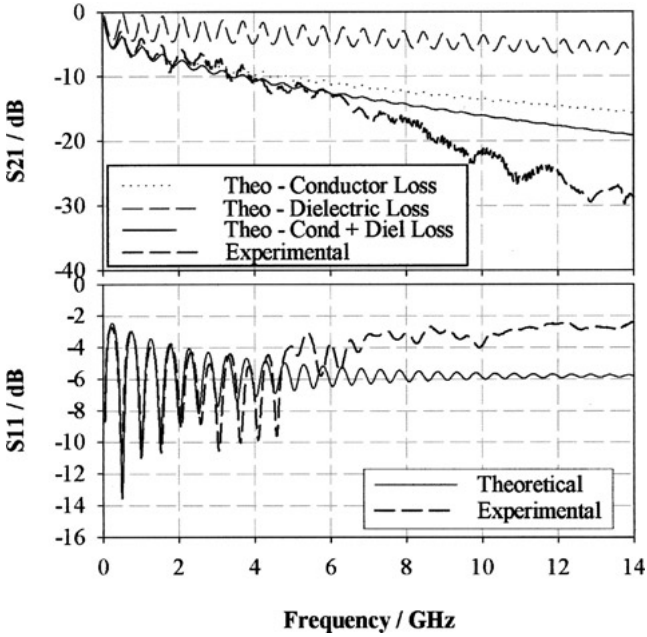


FIGURE 3 Comparison between the theoretical predictions and experimental results for insertion loss and return loss.

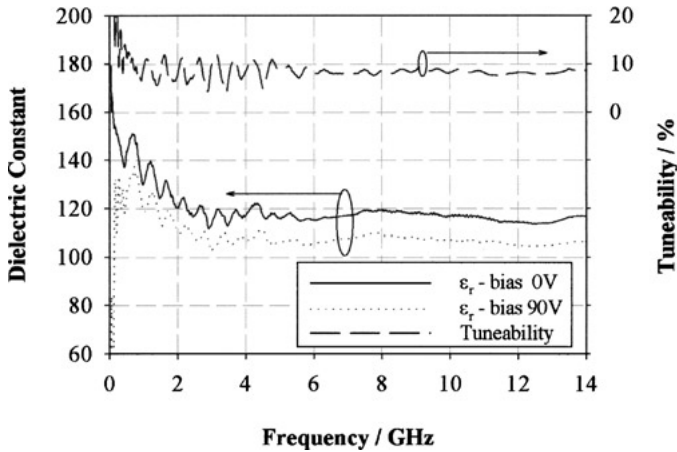


FIGURE 4 The predicted dielectric constant with 90 V and 0 V biasing voltage and the tuneability of the BST thick film.

Figure 4 shows the extracted dielectric constant of the ferroelectric material at the zero bias state and with 90 V of biasing. The effective dielectric constant can be easily computed from the phase constant of the measured phase shifter. The dielectric constant can then be extracted by performing a conformal mapping [7]. It is shown that by applying approximately 2.25 kV/mm of electric field, the dielectric constant changes from 136 to 125, which gives a tuneability of 8.1%. Figure 2 shows that the phase shift is approximately linear to the biasing voltage. This implies that higher tuneability/phase shifter can be expected if higher electric field is applied because the tuneability of the BST thick-film has not reached its saturation.

IV. CONCLUSION

We have presented a thick-film screen-printed ferroelectric phase shifter with high-resolution DGP for the electrodes. The high losses of the phase shifter are mainly attributed to the conductor loss. The material is shown to have low dielectric constant, low loss and high tuneability. It has shown that the phase shifter structure can also be used to extract the dielectric constant of the ferroelectric material over a board frequency range, which is particularly important when designing new materials. We have achieved a minimum gap of 40 μm using DGP, which cannot be achieved in standard screen-printing technology. This allows the realization of novel low voltage

tuneable ferroelectric devices. This shows a very promising future for thick-film ferroelectric materials, which is cheap to manufacture.

ACKNOWLEDGEMENT

The authors thank the European Commission for funding this project under Framework 5.

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