MI017 - Integrated Microwave Frequency Tunable Bandpass Filter using Barium Strontium Titanate Varactors

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Abstract — A bandpass filter for the frequency range of 6-9 GHz, based on tunable interdigital BST varactor is presented. This paper reports the processing steps required to obtain a functional and integrated bandpass filter, which include: via drilling and filling purpose, dielectric deposition, chromium/gold deposition and copper electroplating. Microwave measurements reveal an insertion loss range between 7-11 dB, a 20 dB rejection band, a bandwidth of less than 500 MHz, and 1.73 GHz of frequency tunability.

INTRODUCTION

Ferroelectric materials have been long considered for frequency agile devices due to their strongly nonlinear field dependent permittivty which allows for tuning in devices based on LCR circuits[1]. Ferroelectric thin films present several advantages that make them very attractive for high frequency tunable devices, including low loss, fast tuning speed, and low cost processing [2-4]. Due to these advantages, ferroelectric thin film have been explored for many high frequency devices. BST thin films have been successfully integrated in devices such as AlGaN/Gan high electron-mobility transistors (HEMT) [5], phase shifters [6], and phased array antennas [7].

BST thin films have been previously used in bandpass filters. Nath *et al.* have shown a bandpass filter result for using discret BST varators with 16% frequency tuning from to 2.44 to 2.88 GHz with an insertion loss of 5.1 dB to 3.3 dB respectively, and a bandwidth of 400 MHz [2]. The device presented on this report is a further development of Nath's bandpass filter scaled to higher frequencies with two major processing improvements. For the first improvement, via interconnects are used for direct grounding, thus circumventing the use of epoxy. Via interconnect technologies have been previously investigated for high density packaging in silicon integrated circuits[8]. The vias were filled to provide an even flat surface compatible with subsequent lithography and deposition processing steps. A variety of fillings have been reported; for our purpose a highly conductive and high temperature resistant material was required to withstand the high temperatures used for complex oxide synthesis.

The second improvement integrates the ferroelectric varactors directly in the fabrication step thus eliminating the need to bond discrete varactors into the device. The potential complication of this method is the need to ensure that all three varactors have matching capacitance value, as a deviation beyond 10 % in any of the capacitance values will be detrimental to the filter's performance.

The objective of this paper is to present a methodology to fabricate a fully integrated device for frequency agile microwave circuits based on BST. Although the present study is applied to the fabrication of a bandpass filter, similar strategies can be utilized in other devices. The modelling and characterization of the bandpass filter are presented elsewhere [3, 9].

EXPERIMENTAL PROCEDURE

The alumina substrates were obtained from Coorstek. The vias were drilled and filled with a propietary gold - based mixture suitable for subsequent high temperature processing. The substrate was further polished to make sure the filling is flush with the surface, which facilitates the photolithography step. The barium strontium titanate was deposited by RF magnetron sputtering at 300 ° C for 45 minutes resulting in a thickness of 0.45 □m. The BST was patterned using photolithography and etched off with a 1% HF solution - removing the BST layer from all regions besides the immediate vicinity of the gap capacitors is important for minimizing insertion loss. Subsequently the substrate was annealed in air at 900 ° C for 20 hours. A more detailed report of the BST deposition and characterization can be found in the references [10].

All metallization lines were defined in one lithographic step by photolithography and patterned by lift off . A 70 nm layer of chromium was deposited by sputtering for adhesion purpose, followed by a 350 nm layer of gold deposited by sputtering as well. Following the lift-off, the back of the substrate was metallized with the same metal combination using similar conditions. A second pattening step was employed to mask the inmediate vicinity of the gap capacitors prior to copper electroplating which was used to increase the metal thickness an additional 4000 nm. Masking the gap capacitors is critical given the isotropic nature of electroplating, which will bridge the gaps if plating is allowed in close proximity.

The individual varactors were measured using a HP impedance system, to make sure that all three capacitors values matched at 1 MHz. The device was measured and characterized by HP8510C spectrum analyzer. The procedure used to bias the device as well as the details of the RF measurement can be found in the references [3].

RESULTS

This bandpass filter was designed to operate at a center of frequency of 6 GHz, to provide 25% tuning with respect to the center frequency, to exhibit a bandwith less than 500 MHz and an insertion loss less than 7 dB. The final device showed results, figure 1, close to the desired values, operating at the desired center of frequency of 6 GHz tunable to 7.37 GHz resulting on tuning of 22.7% at 90 V, further biasing is possible and the desired tuning is expected at bias beyond 100 V. The device showed bandwidth of 370-380 MHz during tuning and insertion loss went from 10.69 dB at zero bias to 7.00 dB at 90 V. The insertion loss values are higher than desired and further optimizations are necessary.

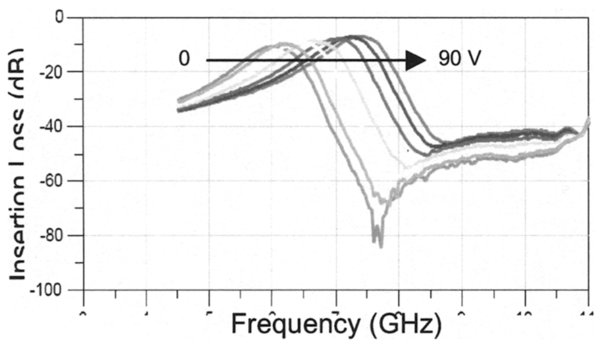

Fig 1. Plot for the insertion loss vs. Frequency. The device was tuned from 0 V to 90 V in steps of 15.

The present work demonstrates the feasibility of integration of tunable varactors into a monolithic microwave circuits. The processing steps presented can be applied on a variety of microwave integrated circuits.

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