Tunable RF filters with graded-composition, MOCVD-deposited BST Capacitors

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Abstract— In this paper, we report the electrical characteristics of compositionally graded BST films deposited by metal organic chemical vapor deposition (MOCVD) on Pt coated sapphire substrates. We characterized the temperature dependent capacitance of graded composition BST capacitors along with single composition BST capacitors. We also report the fabrication and temperature dependent characterization of tunable RF filters fabricated with this technology.

Keywords- Tunable filters, graded composition, BST

I. Introduction

Ferroelectric varactors fabricated with tunable dielectric constant materials such as Barium Strontium Titanate, $Ba_{1-x}Sr_xTiO_3$ (BST) are finding important applications in adaptive radio frequency (RF) components such as voltage controlled oscillators, tunable filters, multiband amplifiers, tunable antennas, and active and passive phase shifters [1-6]. The main problem associated with single composition BST is the temperature dependent permittivity. Compositionally graded BST films are predicted to overcome this problem because the superposition of temperature dependent permittivities of various compositions results in nearly temperature independent characteristics with large tunability [7-10]. In the literature, there are studies on compositionally graded BST deposited by spin-on metalorganic decomposition (MOD), sputtering and laser ablation. MOCVD offers several significant advantages for deposition of compositionally graded BST films, including the capability to deposit a variety of composition profiles, excellent control of film composition and thickness, conformal deposition over device topography and compatibility with large area substrates. In this paper we describe fabrication and characterization of compositionally graded BST capacitors deposited by MOCVD on sapphire substrates. These capacitors are also used to implement tunable combline RF bandpass filters.

II. Sample Preparation

4 inch sapphire substrates were cut into 1 inch square pieces. Titanium film of thickness 30 nm was deposited by DC magnetron sputtering. The titanium film was oxidized in a furnace in flowing oxygen environment at 800 ^{o}C for 30 minutes. Platinum film of thickness 200 nm was deposited on these wafers by DC magnetron sputtering for the bottom electrodes. The bottom electrodes were patterned by standard photolithographic techniques and ion-milling. Graded composition BST films were deposited using a multiple injection flash evaporation MOCVD technique, which is described elsewhere [11]. This technique can produce complex oxide films of nearly any composition profile. The MOCVD process parameters used for the BST films are shown in Table I. The nominal composition profile for the graded composition BST films is shown in Figure 1. After deposition of the BST films, the samples were annealed at a temperature of 800 ^{o}C for one hour in air. Top electrode platinum was deposited by DC magnetron sputtering. The top electrode was patterned with standard photolithographic technique and ion-milling. The structure of the parallel plate capacitors fabricated is shown in Figure 2.

Table I: MOCVD Process Parameters.

Susceptor temperature	700 C
Flash Evaporator temperature	240 C
Gas line temperature	270 C to 290 C
Showerhead temperature	300 C to 320 C
Chamber pressure	3.0 Torr
Flash evaporator push gas flow	300 sccm Ar
Chamber push gas flow	250 sccm Ar
Uniform chamber flow	500 sccm O_2

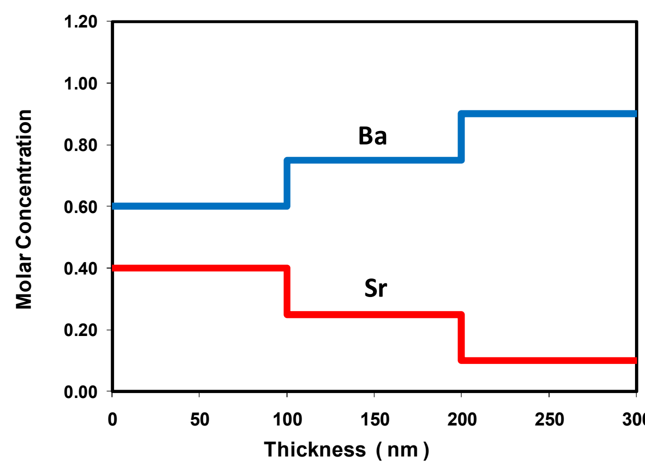

Figure 1: Composition profile of the graded composition BST films produced by the multiple injection flash evaporation MOCVD technique.

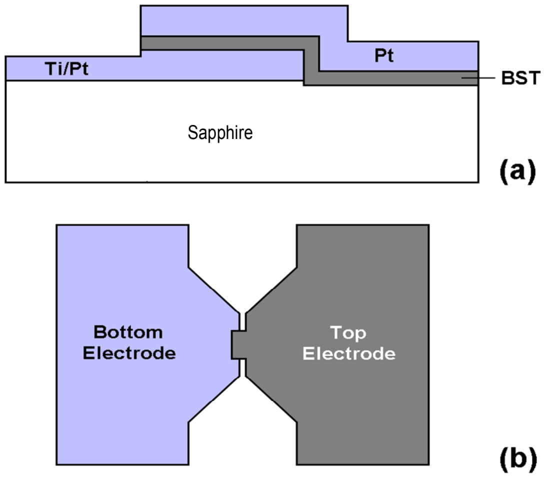

Figure 2: Structure of BST parallel plate capacitors. (a) Cross-sectional structure. (b) Plane view.

III. Results and Discussion

The capacitance versus voltage (C-V) characteristics of the BST capacitors were determined with an HP 4275A LCR meter by mounting the wafer on a vacuum chuck. Figure 3 shows the typical capacitance versus voltage characteristics of a graded composition BST capacitor measured at a frequency of 1 MHz with a small signal voltage of 100 mV. For an applied DC bias voltage of +13 V to -13 V, the tunability of the capacitor is 40%. The tunability of these capacitors is 60% for an applied voltage of +22 V to -22 V.

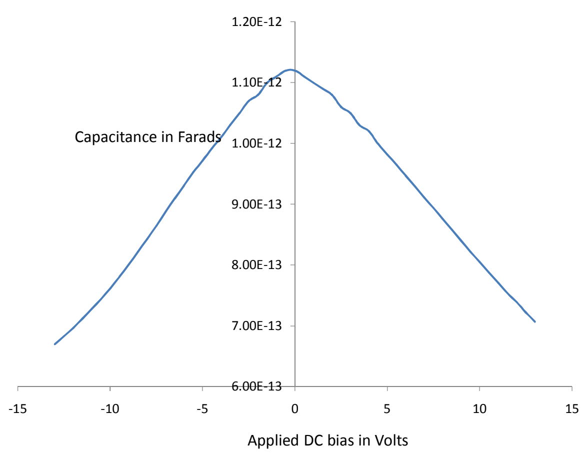

Figure 3: Capacitance versus voltage characteristics of compositionally graded BST capacitors.

Figure 4 shows the temperature dependence of the ratio of capacitance at temperature T to capacitance at 20 ^{o}C for uniform composition $Ba_{1-x}Sr_xTiO_3$ films (where x = 0.10, 0.25, 0.40) and graded composition BST films. Graded composition BST shows the lowest temperature dependence of capacitance compared to uniform composition BST in the temperature range of 20 ^{o}C to 80 ^{o}C.

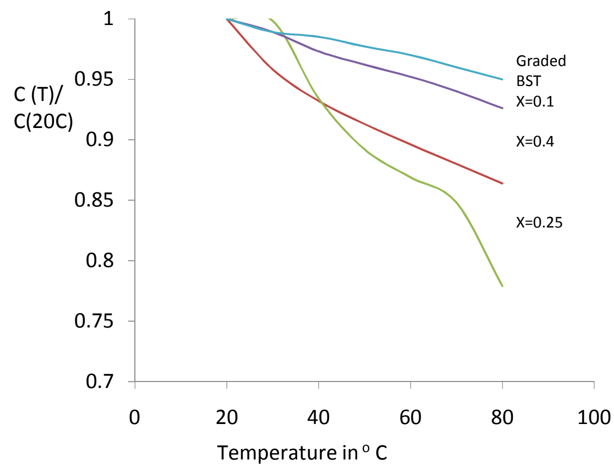

Figure 4: Variation of capacitance with temperature for uniform composition and graded composition BST films.

IV. Design of Tunable Filters

The tunable graded composition BST capacitors were used to implement tunable bandpass filters. Their capacitance varied from 1.2 pF at zero bias voltage to 0.7 pF at $\pm$13 V. Therefore filters fabricated with these capacitors can be tuned with relatively low voltages compared to filters with interdigited electrode capacitors [4]. The schematic of the combline bandpass tunable filter is shown in Figure 5. The coupled resonators of the bandpass filters were loaded with tunable ferroelectric capacitors implemented with graded composition BST films. In order to apply DC bias to the tunable capacitors, linear capacitors were connected in series with them. The linear capacitors are of larger value than the ferroelectric capacitors, so that changes in the capacitance of the tunable capacitors are very effective in tuning the filter characteristics.

Figure 6 shows the prototype of the tunable bandpass filter. The resonators with input and output 50 Ohm microstrips were fabricated on a FR-4 substrate using an LPKF rapid prototyping machine. The tunable graded composition BST parallel plate capacitors fabricated on sapphire substrates were separated using a diamond tipped scribe. The capacitors were attached to the FR-4 substrate using super glue. The tunable capacitors were electrically connected to the microstrip resonators using indium ribbon. The linear surface mount capacitors were attached to the filters by solder reflow technique. SMA connectors for input, output and bias input were soldered to the FR-4 board.

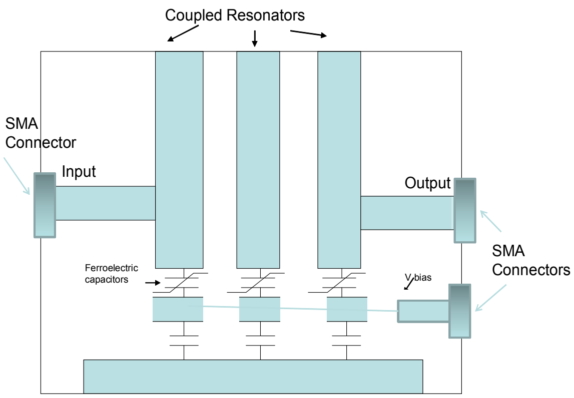

Figure 5: Schematic of the combline bandpass filter.

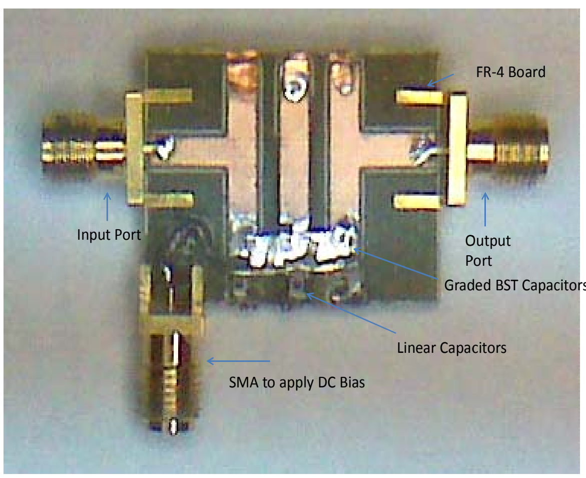

Figure 6: Prototype of the tunable bandpass filter implemented with tunable graded composition BST films.

The bandpass filter was characterized in terms of the scattering parameters S11 and S21 using an Agilent 8080 network analyzer with bias voltage applied through a DC source. Figure 7 shows the return loss (S11) and insertion lass (S21) of the tunable filter implemented with graded composition BST films, with an applied DC bias of 12 V. The center frequency is 4.062 GHz with a 3 db bandwidth of 1.606 GHz. The minimum insertion loss in the pass band is -5.92 db and the maximum insertion loss is -36.9 db. Table II shows the electrical characteristics of the tunable filter such as center frequency, minimum insertion loss, 3 db bandwidth and maximum return loss in the pass band at various bias voltages.

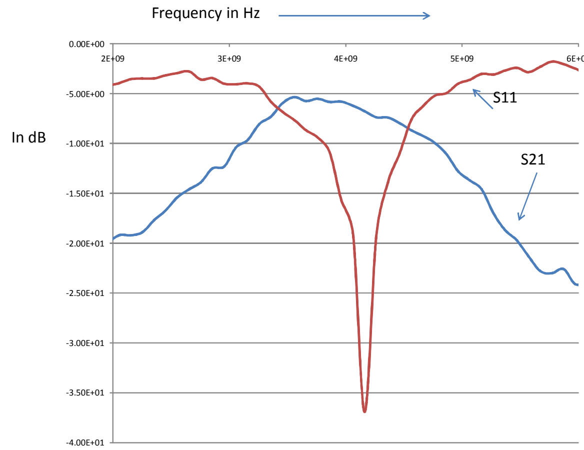

Figure 7: Return loss (S11) and insertion loss (S21) of the tunable filter implemented with graded composition BST films.

Table II: Tuning Characteristics of Bandpass Filter

Tuning Voltage	Center Frequency	Minimum insertion loss	Band width	Maximum return loss
0V	3.710 GHz	-6.31db	.905 GHz	-18.7db
3V	3.730 GHz	-6.35db	1.105 GHz	-20.9 db
6V	3.761 Hz	-6.18db	1.206 GHz	-22.8 db
9V	3.810 GHz	-5.59 db	1.220 GHz	-25.9 db
12V	4.062 GHz	-5.92 db	1.606 GHz	-36.9 db

V. Conclusions

Graded composition BST films were deposited using a multiple injection flash evaporation MOCVD technique on sapphire substrates with platinum electrodes. The resulting parallel plate capacitors fabricated using these films show tunability over 60% at ± 22 volts. These graded composition BST capacitors show a significantly lower temperature dependence of capacitance, compared to uniform composition BST films. Tunable combline RF bandpass filters fabricated using these tunable BST capacitors can be tuned with low voltage.

VI. Acknowledgement

This project was supported, in part, by the US Army research Office through Contract # W911NF08-C-0124.

VII. References

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