Microwave Characterization of Thin Film BST Material Using a Simple Measurement Technique

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***Abstract* — Thin film barium strontium titanate (BST) in the parallel plate capacitors is characterized at microwave frequencies using a simple measurement technique. Short standards are fabricated on the same wafer as the BST capacitors to remove the parasitics of pads, lines, discontinuities and electrodes. The dielectric constant of the patterned BST thin film in the parallel plate capacitor is found to be frequency independent up to 10 GHz. The average loss tangent of BST thin film for the sample under test is approximately 0.006 and also found to be frequency independent up to 10 GHz.**

I. Introduction

With the rapid growth in various communication systems including satellites, bluetooth and optical networks, the demand for tunable circuits at RF and microwave frequencies has increased. BST, a ferroelectric film whose dielectric constant can be controlled by the application of a DC electric field, has shown great promise for the fabrication of tunable RF and microwave circuits such as phase shifters [1]-[2], tunable filters [3]-[4] and antennas [5]. Many RF and microwave applications need the BST in the parallel plate capacitor form to obtain higher tunability and lower bias voltage [1], [3]. The electrical properties of thin film BST in this form greatly depend on the BST composition (Ba/Sr ratio and Ti composition), the bottom and top electrode materials, the film thickness, and the process temperature. It is very important to develop a simple and fast measurement technique that can determine the properties of low loss BST properties in the parallel plate capacitors. This will help the material scientists to optimize the thin film BST growth.

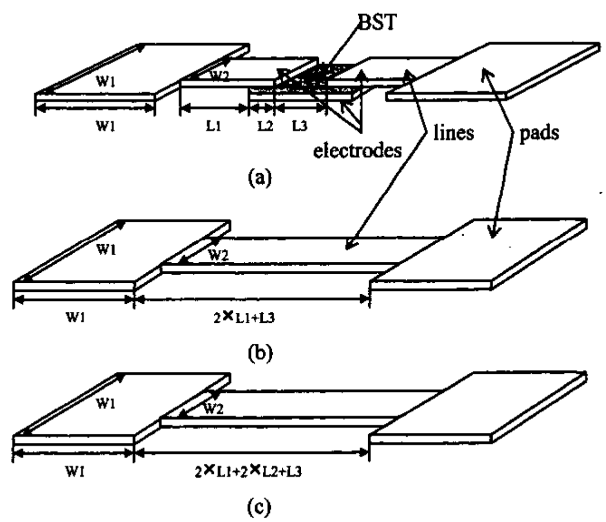

Fig. 1 (a) the BST capacitor and standards (b) short #1 and (c) short #2 are fabricated on the same wafer

At microwave frequencies, usually the conductor loss due to the interconnects and electrodes is dominant for low loss thin film BST capacitors [1], [6]-[7], and must be carefully extracted for an accurate determination of BST loss tangent. Furthermore, the probe contact resistance increases the inaccuracy of loss tangent extraction [8]. A simple approach presented here overcomes these difficulties. In this approach, the parallel plate capacitors as well as short standards are fabricated on the same wafer (Fig. 1). Reflection coefficient (one-port S-parameter) measurement is performed on the two shorts and the capacitor, individually. Then the input impedance (Z) is obtained using

$$Z = Z_0 \frac{1+S_{11}}{1-S_{11}} \quad (1)$$

where Z_0 is the characteristic impedance of the vector network analyzer (VNA), and S_{11} is the reflection coefficient. Z_C, Z_{S1}, and Z_{S2} represent the input impedance of the capacitor, short #1 and short #2 respectively. Z_{S1} is used to extract the parasitics of the pads, lines and the discontinuity between the pads and lines. By subtracting Z_{S1} from Z_{S2}, characteristics of the line having the same length as the capacitor electrodes are obtained. Thus the BST characteristics can be got by removing the interconnects and electrode. The effect of probe contact resistance is also reduced due to the impedance subtraction.

No special BST processing is required for this measurement technique. The measurement is performed on the devices that will be used in the actual circuits, such as tunable filters [9]. This measurement can provide fast and accurate information about the key devices in a tunable circuit.

II. MEASUREMENT TECHNIQUE

As shown in Fig. 1, the capacitor is formed by two parallel plate capacitors in series. Note that the standards have the same size of pads and lines as that of the capacitors. The whole circuit is fabricated on a 1-mm thick quartz substrate. The bottom electrode of 1000 Å-thick Pt was deposited on the quartz substrate. BST was grown by metalorganic chemical vapor deposition (MOCVD) method and is 700 Å thick. MOCVD is the deposition method of choice for the fabrication of low loss thin film BST. It provides excellent composition control, large area coverage, and the potential for large area homogeneity and conformal coating of complicated topographies. Top electrodes (1000 Å thick) completing the parallel plate capacitor structure, were deposited by either sputtering or electron-beam evaporation.

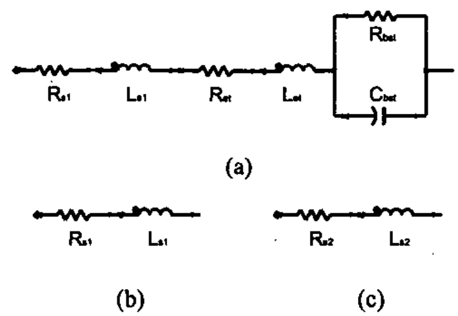

Fig. 2 Equivalent circuits of the on wafer (a) capacitor, (b) short #1 and (c) short #2

A VNA with a signal-ground (S-G) probe is used to measure the reflection coefficient of the parallel plate capacitor and short standards. The difference between the two shorts is that short #1 has the line length of $2\times L_1 + L_3$, while short #2 has $2\times L_1 + 2\times L_2 + L_3$. Short #1 is used to extract the paracitics of the pads, lines and the discontinuity between the pad and line. Note that the bottom interconnecting line (L_3) is also extracted. The equivalent circuits of the capacitor and two shorts are shown in Fig. 2. Therefore, the impedances are given by

$$Z_C = Z_{S1} + Z_{et} + \frac{R_{bst}}{1 + j\omega R_{bst} C_{bst}} \quad (2)$$

$$Z_{S1} = R_{S1} + j\omega L_{S1} \quad (3)$$

$$Z_{S2} = R_{S2} + j\omega L_{S2} \quad (4)$$

$$Z_{et} = R_{et} + j\omega L_{et} \quad (5)$$

where, R_{S1}, L_{S1}, R_{S2}, and L_{S2} are the series resistance and inductance of short #1 and short #2, respectively and Z_{et} is the impedance of the capacitor electrodes. R_{bst} is the shunt resistance of BST which is given by

$$R_{bst} = \frac{1}{\omega C_{bst} \tan\delta} \quad (6)$$

where C_{bst} is the capacitance of the two parallel plate capacitors in series, $\tan\delta$ is the loss tangent of BST, and ω is the angular frequency. The impedance of the line ($2\times L_2$) is given by

$$Z_{L2} = R_{L2} + j\omega L_{L2} = Z_{S2} - Z_{S1} \quad (7)$$

The value of R_{et}/R_{L2} and L_{et}/L_{L2} can be calculated and found to be approximately 66.5% for our capacitors.

By solving (2), (3), (4), (5), (6) and (7), the BST loss tangent and the device capacitance are obtained:

$$\tan\delta = \frac{\mathrm{Re}[Z_C - Z_{S1} - a\times(Z_{S2} - Z_{S1})]}{\mathrm{Im}[Z_{S1} + b\times(Z_{S2} - Z_{S1}) - Z_C]} \quad (8)$$

$$C_{bst} = \frac{1}{\omega\,\mathrm{Im}[Z_{S1} + b\times(Z_{S2} - Z_{S1}) - Z_C](1 + \tan\delta^2)} \quad (9)$$

where, $a = R_{et}/R_{L2}$ and $b = L_{et}/L_{L2}$.

III. Results

The reflection coefficient measurement of BST capacitors and the short standards were performed using a HP8510C network analyzer. To minimize the measurement error, ten capacitors and standard shorts with the same dimensions were measured. The average impedance values (Z_C, Z_{S1} and Z_{S2}) were used to calculate the capacitance and loss tangent.

Figs. 3 and 4 show the capacitance and BST loss tangent obtained for the parallel plate capacitor, respectively. As can be seen, the

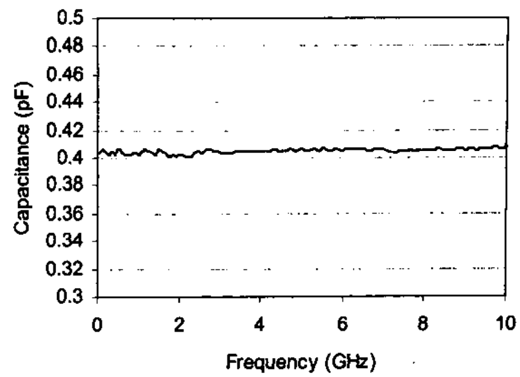

Fig. 3 BST capacitance versus frequency

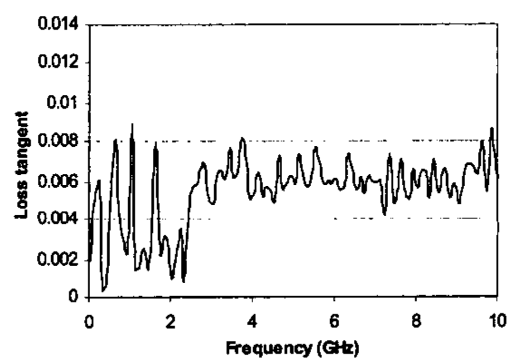

Fig.4 BST loss tangent versus frequency

capacitance is almost frequency independent at least up to 10 GHz. Thus the dielectric constant of the BST film can be treated as frequency independent up to this frequency. In addition, the BST loss tangent is also almost frequency independent. The fluctuation of loss tangent at low frequencies is due to the limited sensitivity of the instrument at these frequencies [8]. The average value of the loss tangent is approximately 0.006 up to 10 GHz.

V. CONCLUSION

A simple measurement technique for the characterization of BST thin film in parallel plate capacitor at RF and microwave frequencies is developed. No special BST process is required for this measurement technique. The dielectric constant and loss tangent are found to be frequency independent up to 10 GHz.

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