Fabrication and Characterization of Tunable Bandpass Filter using BST Thin Films

Il-Doo Kim, Duk-su Kim, Kyu-Sung Park, and Ho-Gi Kim

Abstract

In this work, a CPW resonator was designed and fabricated to investigate the basic microwave properties, such as effective dielectric constant, of BST thin films. Their properties were used as basic data to simulate and design CPW tunable bandpass filter. We also report on gold/$Ba_{0.5}Sr_{0.5}TiO_3$(BST) ferroelectric thin film C-band tunable bandpass filters(BPFs) designed and fabricated on magnesium oxide substrates using CPW structure. The 2 pole filter was designed for a center frequency of 5.88 GHz with a bandwidth of 9 %. The BST based CPW filter offers a high sensitivity parameter as well as a low loss parameter. The tuning range for the bandpass filter with CPW structure was determined to be 170 MHz.

Key Words : BST, Coplanr waveguide, Resonator, Filter, Tuning

1. INTRODUCTION

In the past few years, the use of high permittivity ferroelectric materials such as $Ba_{1-x}Sr_xTiO_3$ (BST) and $SrTiO_3$ (STO) has been widely studied due to an increasing need for smaller size, lighter weight, higher power and lower cost frequency agile components. Examples of tunable microwave device application include electronically tunable mixers, oscillators, phase shifters, and filters.[1-5] The frequency agile property of ferroelectric thin films is due to the nonlinear dc electric field dependence of their relative dielectric constant.

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The most critical properties that need to be optimized for tunable microwave devices application are the magnitude of the change in the dielectric constant as a function of the applied electric field and dielectric loss at microwave frequencies. Since the figure of merit (FOM) generally accepted is defined by a ratio of tunability to loss tangent, higher tunability and lower loss tangent are highly desirable to fabricate a high-efficient tunable device. However, as it is not easy to obtain high tunability and low loss tangent simultaneously, compromises are needed between them in order to optimize the reasonable tunability and loss tangent of the BST tunable devices.

In this work, we investigated the modeling and fabrication of $Ba_{0.5}Sr_{0.5}TiO_3$ (henceforth BST) ferroelectric thin film based frequency agile CPW filter. This work demonstrates a potential use of ferroelectric thin-films in passive microwave components at Wireless LAN frequencies.

2. EXPERIMENTAL

The BST films were grown by pulsed laser deposition (PLD) employing a KrF excimer laser (=248 nm) using the $(Ba_{0.5}Sr_{0.5})TiO_3$ target. The films were deposited at a laser repetition rate of 4 Hz with a laser pulse energy density of 1.5 J/cm^2. A 1 ㎛ metal ground plane was deposited to complete the circuit fabrication. To overcome the disadvantage of a pure gold contact,[6-7] we employ a thin layer of titanium (30 nm) to improve the surface adhesion and a thick layer of platinum (600 nm) as a diffusion barrier and adhesion layer, after then a thick layer of gold (370 nm) for its high conductivity and stability was deposited. The final geometries of electrode were achieved by standard photolithography and lift off processing. The geometry of the multilayered CPW structure is shown in Fig. 1.

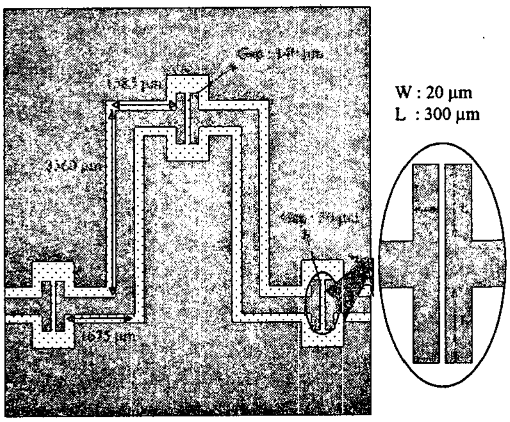

Fig. 1. Top view image of designed CPW filter

The microwave characterization was performed using an HP 8510C network analyzer to measure transmission scattering parameter (S_{21}). For tuning measurements, a voltage bias is applied between the centerline and the ground planes.

3. RESULTS AND DISCUSSION

The X-ray diffraction analysis for the BST thin film [Fig. 1] grown on MgO substrate exhibits a phase pure crystalline film. The figure reveals that the (100) plane is dominant in the BST films grown on this stack. Namely, the BST films were confirmed to be single-phase a-axis oriented normal to the substrate from the measurement of the XRD θ-2θ scan.

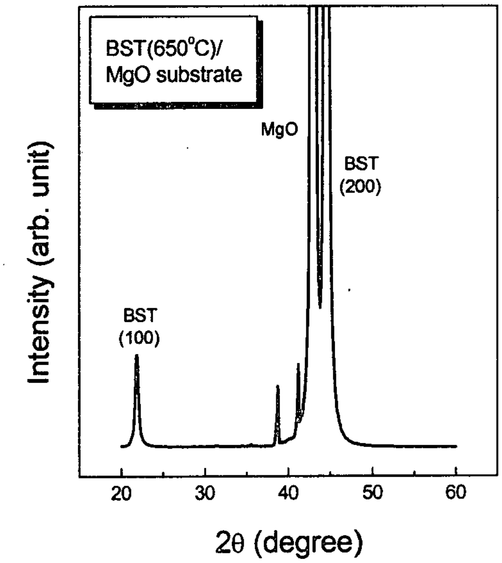

Fig. 2. XRD pattern of BST film grown on MgO substrate

In order to accurately measure and characterize the basic properties of BST films in microwave frequency range prior to the design of tunable bandpass filter, the effective permittivity of BST thin film was determined from the design and measurement of the end-gap line resonator with coplanar waveguide (CPW) structure. The end-gap CPW resonator was designed with wide gap for the resonance information. The resonator was fed by capacitive coupling gaps of 10 ㎛. The width of the signal conductor and the spacing between the signal conductor and the ground plane was taken to be 30 and 110 ㎛, respectively.

The resonator was designed with a center frequency of 12 GHz through IE3D's simulation process. Just before each set of S-parameter measurements, we calibrated the microwave test system using calibration kit. SOLT (short-open-load-thru) calibration was conducted.

Bias dependence of S_{21} of the resonator is shown in Fig. 3. The sample was tuned using the bipolar biasing scheme through bias tee. The resonant frequencies are 14.695 GHz, 14.75 GHz, 14.777 GHz, and 14.797 GHz with the bias of 0 V, 10 V, 20 V, and 30 V, respectively. The center frequency shift is defined as ($f_{vmax} - f_o$), where f_{vmax} is the center frequency of the resonator at maximum applied voltage, and f_o is the center frequency of the resonator at no bias. The corresponding effective dielectric constant for the resonator with center frequency of 14.695 GHz was 7.601. These effective dielectric constant data is adopted for the design of the tunable bandpass filter using BST thin films. The frequency tunability range was 102 MHz at an applied voltage of 30 V. As DC bias voltage increased, resonant frequency also increased due to the decrease of dielectric constant value of BST thin film.

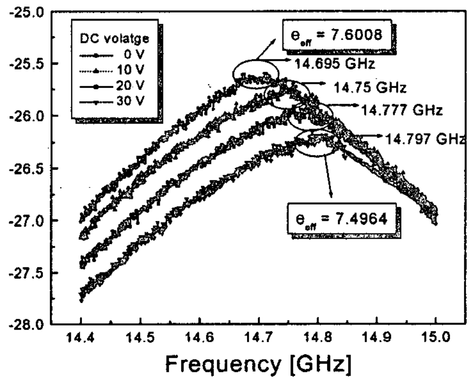

Fig. 3. DC bias dependent frequency response of CPW resonator

The theoretical modeling and experiment of the filters on MgO substrates were performed.

Figure 4 shows the simulation results of the tunable bandpass filter with CPW structure. The 2 pole CPW (Coplanar Waveguide) filter was designed for a center frequency of 5.88 GHz and a bandwidth of 9 %. The corresponding insertion loss was 1.14 dB.

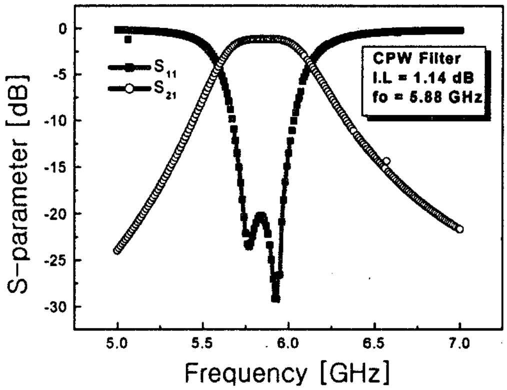

Fig. 4. Theoretical simulation results for Au/BST/MgO filter with CPW structure.

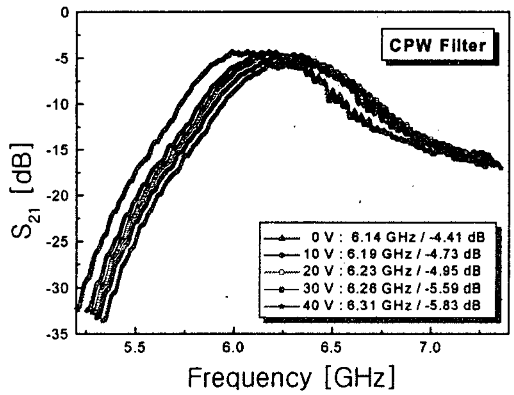

Fig. 5. Bias dependence of S_{21} for the tunable bandpass filter of CPW structure

As shown in Fig. 5, fabricated CPW filter had a center frequency of 6.14 GHz and the corresponding insertion loss is 4.41 dB at zero bias voltage. These higher insertion losses are primarily due to large tan δ in the BST films[8,9] and the change of patterned geometry during the photolithography process. In addition, when comparing the modeled and experimental data, one should realize that IE3D's analysis assumes dielectric constant of BST to be the same across the sample, while in reality, biasing the transmission line causes local changes in dielectric constant of BST and loss tangent. Other factor such as the conductor layer quality (Au/Pt/Ti) also contributes adversely to the measured insertion losses.[10,11] Because dielectric loss in the ferroelectric thin film play as crucial role in determining the performance of electrically tunable devices, therefore further studies are needed to improve loss property. With an applied voltage of 40V, the center frequency for the CPW filter was measured to be 6.31 GHz and insertion loss was observed to be 5.83 dB. From the experiment, the tuning range for the CPW filter was determined to be 170 MHz.

4. CONCLUSIONS

A planar tunable coplanar waveguide (CPW) bandpass filter has been realized using nonlinear dielectric BST ferroelectric thin film in this research. Experimental results indicated that the ferroelectric tunable CPW filter was tunable by more than 3% at bias voltage levels of 40V. The BST based CPW filter offers a high sensitivity parameter as well as a low loss parameter. This work demonstrates a potential use of ferroelectric thin-films in passive microwave components at Wireless LAN frequencies.

ACKNOWLEDGEMENT

This work was partly supported by the Brain Korea 21 project. The authors are grateful Dr. Jong-Chul Lee of Kwangwoon Univ. for his help in simulation process. The authors also thank Ki-Byoung Kim and Tae-Soon Yun for helpful suggestions and discussions during the course of this work.

REFERENCES

[1] O.G. Vendik, E. K. Hollmann, A. B. Kozyrev, and A. M. Prudan, J. Superconductivity. 12 (1999) 325.

[2] O. G. Vendik, L. T. Ter-Martirosyan, A. I. Dedyk, S. F. Karmanenko, and R. A. Chakalov: Ferroelectrics, 144 (1993) 33.

[3] C. M. Jackson, J. H. Kobayashi, D. Durand, and A. H. Silver, Microwave J. 12 (1992) 72.

[4] A. T. Findikoglu, C. Doughty, S. M. Anlage, Qi Li, X. X. Xi, and T. Venkatesan, Appl. Phys. Lett. 63 (1993) 3215.

[5] D. Galt, J. C. Price, J. A. Beall, and R. H. Ono, Appl. Phys. Lett. 63 (1993) 3078.

[6] G. M. Smith, D. V. Faobes, R. M. Lammert, and J. J. Coleman, Appl. Phys. Lett. 67 (1995) 3847.

[7] Yuxiao Zeng, Y. L. Zou, T. L. Alford, F. Deng, S. S. Lau, T. Laursen and B. Manfred Ullrich, J. Appl. Phys. 12 (1997) 7773.

[8] J. S. Horwitz, W. Chang, A. C. Carter, J. M. Pond, S. W. Kirchoefer, D. B. Chrisey, J. Levy and C. Hebert, Integrated Ferroelectrics. 22 (1998) 279.

[9] M. W. Cole, P. C. Joshi, M. H. Ervin, M. C. Wood and R. L. Pfeffer, Thin Solid Films. 374 (2000) 34.

[10] G. Subramanyam, IEEE. Microwave Theory and Techniques. 48 (2000) 525.

[11] S. W. Kirchoefer, J. M. Pond, A. C. Carter, W. Chang, K. K. Agarwal, J. S. Horwitz, and D. B. Chrisey. Microwave and Optical Technology Lett. 18 (1998) 168.