Tunable Band-pass Filters using $Ba_{0.5}Sr_{0.5}TiO_3$ Thin Films for Wireless LAN Application

무선랜 대역용 $Ba_{0.5}Sr_{0.5}TiO_3$ 박막을 이용한 가변 대역 통과 여파기

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Abstract

In this paper, the performance of Au / $Ba_{0.5}Sr_{0.5}TiO_3$ (BST) / Magnesium oxide (MgO) two-layered electrically tunable band-pass filters (BPFs) is demonstrated. The devices consist of microstrip, coplanar waveguide (CPW), and conductor-backed coplanar waveguide (CBCPW) structures. These BST thin film band-pass filters have been designed by the 2.5 D field simulator, IE3D, Zeland Inc., and fabricated by thin film process. The simulation results, using the 2-pole microstrip, CPW, and CBCPW band-pass filters, show the center frequencies of 5.89 GHz, 5.88 GHz, and 5.69 GHz, and the corresponding insertion losses are 2.67 dB, 1.14 dB, and 1.60 dB, with 3 %, 9 %, and 7 % bandwidth, respectively. The measurement results show the center frequencies of 6.4 GHz, 6.14 GHz, and 6.04 GHz, and their corresponding insertion losses are 6 dB, 4.41 dB, and 5.41 dB, respectively, without any bias voltage. With the bias voltage of 40 V, the center frequencies for the band-pass filters are measured to be 6.61 GHz, 6.31 GHz, and 6.21 GHz, and their insertion losses are observed to be 7.33 dB, 5.83 dB, and 6.83 dB, respectively. From the experiment, the tuning range for the band-pass filters are determined as about 3 %~8 %.

Key words : $Ba_{0.5}Sr_{0.5}TiO_3$ Thin Film, Tunable Band-pass Filters, Microsrtip, CPW, CBCPW

요 약

본 논문은 $Ba_{0.5}Sr_{0.5}TiO_3$(BST) 박막을 이용한 대역 통과 여파기를 설계, 제작한 것으로 마이크로스트립과 코플래너 웨이브가이드(CPW), CBCPW 전송 선로 구조에서 각 구조의 여파기 특성을 비교하였다. 제작된 여파기는 전압 0V 인가시 각각 6.4 GHz, 6.14 GHz, 6.04 GHz의 중심 주파수와 6 dB, 4.41 dB, 5.41 dB의 삽입 손실이 측정 되었으며, 40V 인가시 중심 주파수 6.61 GHz, 6.31 GHz, 6.21 GHz와 삽입 손실 7.33 dB, 5.83 dB, 6.83 dB로 나타났다. 본 논문에서 제작된 각각의 대역 통과 야파기는 가변 범위가 약 3 %~8 %이며, 무선랜 대역에 응용할 수 있도록 설계 및 제작되었다.

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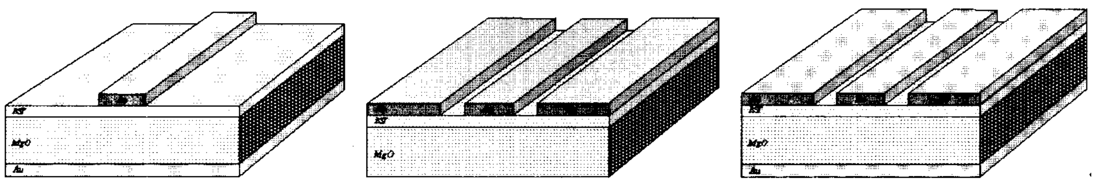
Ⅰ. Introduction

In the past few years, the high-permittivity ferroelectric thin film materials in microwave devices have been widely investigated due to an increasing need for higher performance, smaller size, lighter weight, lower cost frequency and phase agile components than conventional ones. Research outputs in this microwave engineering including field-dependent tunable varactor diodes, phase shifters, tunable resonators, and filters have been demonstrated[1~6]. Ferroelectrics exhibit a non-linear characteristic, in which relative dielectric permittivity can be fast controlled by applied dc electric field [3],[6]. Electric fields of non-linearity for the ferroelectric thin-film, BST($Ba_{0.5}Sr_{0.5}TiO_3$) can be applied to the electrically tunable active and passive microwave devices. The design of microwave devices using ferroelectric thin film has many advantages such as high speed, high power capability, lower cost and size, application to millimeter and sub-millimeter frequencies as well as a possibility to be operated at even much higher frequencies. For such application, it is important to select materials with low microwave loss and high dielectric tunability. A BST ($Ba_xSr_{1-x}TiO_3$) has been considered as one of the candidate materials satisfying the necessary conditions. Recent improvement in thin film processing and device integration gives controllability in microwave loss close to the limit required for practical competition with ferrite or another tuning technologies.

In this paper, tunable band-pass filters using BST($Ba_{0.5}Sr_{0.5}TiO_3$) thin films for wireless LAN application with microstrip, CPW, and CBCPW structures are suggested, implemented, and compared with each other for their microwave characteristics.

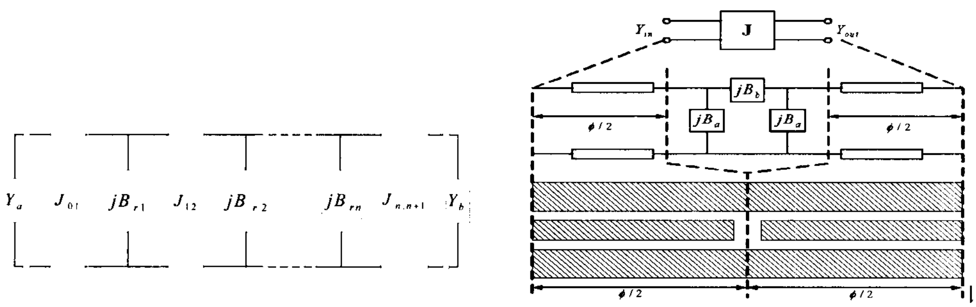
Ⅱ. Filter Theory

Fig. 1 shows the basic structures for Microstrip, CPW, and CBCPW to be used for the design of the tunable filters. For the design of the filters using the same resonator, inverter theory can be applied[7]. The



(a) Microstrip (b) CPW (c) CBCPW

Fig. 1. Proposed transmission line structures.



(a) BPF of J-Inverter (b) J-Inverter of CPW Gap

Fig. 2. Admittance Inverters.

number of inverters used in filter theory is one more than that of the resonators. The advantage of band-pass filter using inverters is its variable impedance while it provides asymmetrically terminated impedance values of input and output. Fig. 2(a) shows a basic structure of BPF using J-Inverter. Fig. 2(b) shows the equivalent circuits for a CPW gap using J-Inverter. The values of J-Inverters are given in equations (1)~(3).

$$J_{01}=\frac{\sqrt{Y_a B_{r1}(w)}}{g_0(w_1'g_1)},\quad J_{j,j+1}=\frac{\sqrt{B_{rj}(w)B_{rj+1}(w)}}{(w_1'g_j)(w_1'g_{j+1})},$$

$$J_{n,n+1}=\frac{\sqrt{B_m(w)Y_b}}{(w_1'g_n)g_{n+1}} \qquad (1)$$

$$J_{01}/Y_0=J_{n,n+1}/Y_0=\sqrt{\pi W/2g_0g_1\omega'1},$$

$$J_{j,j+1}/Y_0=\pi W/(2\omega'_1\sqrt{g_jg_{j+1}})\ J\neq 0,n \qquad (2)$$

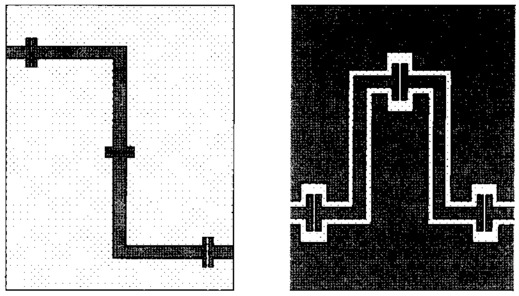
$$\omega_0=\sqrt{\omega_1\omega_2},\ w=\frac{\omega_2-\omega_1}{\omega_0},$$

$$\omega'=\frac{\omega'_1}{w}\left(\frac{\omega}{\omega_0}-\frac{\omega_0}{\omega}\right) \qquad (3)$$

where ω, ω' are pass band and low band domain angular frequencies, and ω_0, ω_1, ω_2 are BPF's center, lower, and upper cutoff frequencies, respectively[7]. From these equations, the values of J and B can be obtained and then the gap of the resonator can be given from the property of the BPF with these values. The value of coupling (inverter) can be simulated and optimized by the variation of gap.

Ⅲ. Band-pass Filter Design

The epitaxial BST($Ba_{0.5}Sr_{0.5}TiO_3$) ferroelectric thin film is prepared by pulsed laser deposition(PLD) on MgO(ε_r = 9.6, h = 500 μm) single crystalline substrate. The dielectric constant (ε_r) of BST thin film is calculated as about 300 through characterization of a CPW end-gap resonator. Also, the effective dielectric constant (ε_{eff}) of MgO substrate and BST thin film is calculated as about 7.601 without bias voltage. The BST thickness is about 0.5 μm. To enhance the adhesion between BST thin film and gold electrode, thin Pt/Ti/Au adhesion layers are deposited by sputtering prior to Au deposition. The Au thickness is about 1 μm. The size of BPFs is 10 mm × 10 mm. Fig. 3 shows the band-pass filter structures proposed in this paper. These BPFs are consisted of end-coupled line structures and the



(a) A Microstrip BPF (b) CPW and CBCPW BPFs

Fig. 3. The BST band-pass filters.

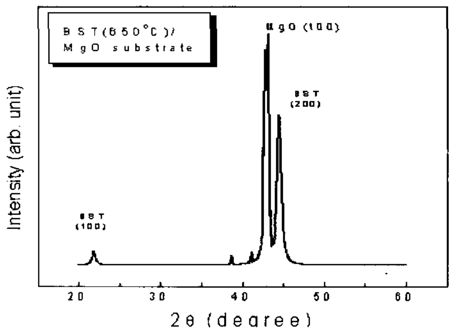


Fig. 4. XRD-pattern of BST thin film.

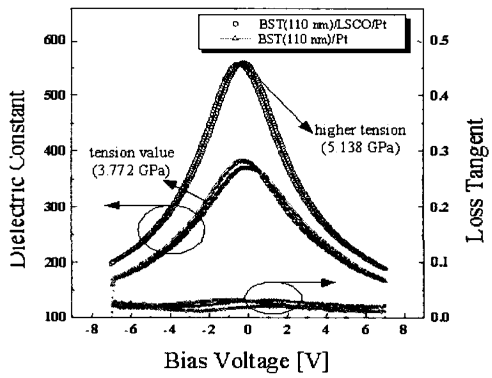
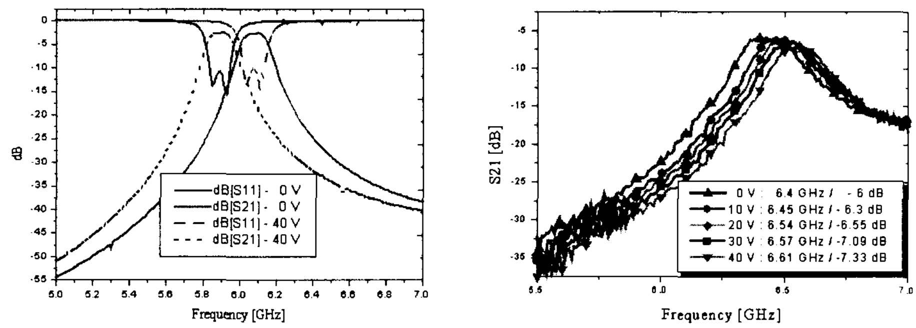


Fig. 5. Bias voltage vs. dielectric constants of the BST thin film.

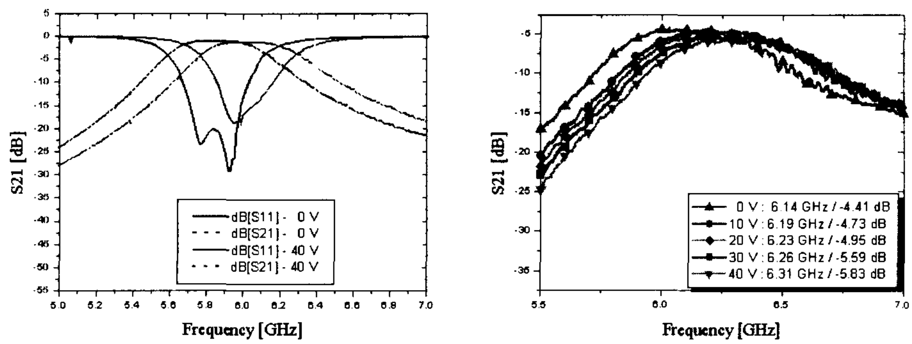
broad section of the gap is adopted for high coupling efficiency. The length of three band-pass filters is 179.82° of the center frequency. Since a parallel coupling resonator is hard to be realized with CPW and CBCPW structures, a series end gap types of resonators are tried to implement BPFs.

Fig. 4 shows X-ray diffraction pattern of the BST thin films deposited by PLD. The film has been grown on MgO(100) substrate. Very small line-width of BST (200) peak clearly indicates that the film is of very high crystalline quality. The change in the value of dielectric constant depending on the applied bias voltage for the BST thin film is shown in Fig. 5. As the applied voltage is increased, the dielectric constant of BST thin film is decreased and tangent loss is improved.

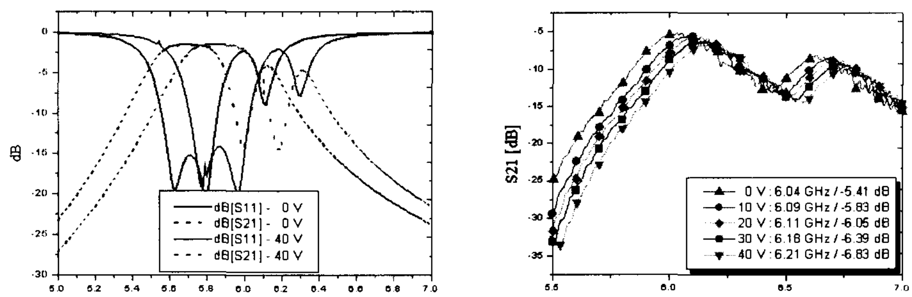
The band-pass filters suggested in this paper are simulated by the field simulator, IE3D and the results are shown in Fig. 6 with measurement data. The simulation results show the center frequencies of



(a) Simulation and Measurement data for the Microstrip BPF.



(b) Simulation and Measurement data for the CPW BPF.



(c) Simulation and Measurement data for the CBCPW.

Fig. 6. Simulation and Measurement results for the BPFs.

Table 1. The comparison of simulation and measurement results for microstrip, CPW, and CBCPW BPFs.

		Applied voltage [V]	Center frequency [GHz]	Insertion loss [dB]	Bandwidth [GHz]
Microstrip	Simulation	0	5.89	2.67	5.81 ~ 5.97
		40	6.08	2.89	6 ~ 6.16
	Measurement	0	6.4	6	6.31 ~ 6.56
		40	6.61	7.33	6.44 ~ 6.68
Coplanar waveguide	Simulation	0	5.88	1.14	5.62 ~ 6.14
		40	6.04	1.9	5.77 ~ 6.32
	Measurement	0	6.14	4.41	5.81 ~ 6.46
		40	6.31	5.83	5.98 ~ 6.66
Conductor-backed CPW	Simulation	0	5.69	1.60	5.49 ~ 5.89
		40	5.85	1.63	5.63 ~ 6.07
	Measurement	0	6.04	5.41	5.88 ~ 6.26
		40	6.21	6.83	6.01 ~ 6.34

5.89 GHz, 5.88 GHz, and 5.69 GHz for Microstrip, CPW, and CBCPW structures and the corresponding bandwidths are 3 %, 9 %, and 7 %, respectively. Measurement data show the center frequencies of 6.4 GHz, 6.14 GHz, and 6.04 GHz and the insertion losses are 6 dB, 4.41 dB, and 5.41 dB for each BPF, respectively. Microwave performances for the band-pass filters are measured using a HP 8510C Network analyzer and a probe station at room temperature and the frequency range are 5 GHz~7 GHz with the applied bias voltage up to 40 V.

From the figures, the center frequencies of the BFPs are moved toward higher band with increasing bias voltage. It was already anticipated from the Fig. 5. With increasing bias voltage, the decrease in dielectric constant of BST thin film means the increase in center frequency of BST band-pass filters.

The characteristics of the BPFs of microstrip, CPW, and CBCPW structures are summarized in Table 1. The differences between the simulation and measurement results are believed to be due to the fabrication margin in process and the change of reactance by wire bonding from CPW to microstrip adapter. It is expected that the wider bandwidth can be obtained with the bias voltage of higher than 40 V to the BST filters. To reduce activation voltage, the optimum condition of composition between Ba and Sr and the insertion of MIM capacitors into the BST structure are needed to be studied.

Ⅳ. Conclusion

In this paper, ferroelectric thin film ($Ba_xSr_{1-x}TiO_3$) tunable 2-pole band-pass filters have been demonstrated using the conductor/ferroelectric/ dielectric two-layered microstrip, coplanar waveguide, and conductor backed coplanar waveguide configuration. The center frequencies of designed microstrip, CPW, CBCPW band-pass filters are 5.89 GHz, 5.88 GHz, and 5.69 GHz and the corresponding insertion losses are 2.67 dB, 1.14 dB, and 1.60 dB, respectively. The measured center frequencies for the microstrip, CPW, and CBCPW BPFs are 6.4 GHz, 6.14 GHz, and 6.04 GHz and the corresponding insertion losses are 6 dB, 4.41 dB, and 5.41 dB without any bias voltage, respectively. With the bias voltage of 40 V, the center frequencies for the microstrip, CPW, and CBCPW BPFs are measured to be 6.61 GHz, 6.31 GHz, and 6.21 GHz and the corresponding insertion losses are observed to be 7.33 dB, 5.83 dB, and 6.83 dB, respectively. From the experiment, the tuning ranges for each band-pass filter are determined to be about 210 MHz, 170 MHz, and 170 MHz, respectively.

Among the three BST BPFs, the CPW BPF has the lowest insertion loss while the microstrip BPF has the most wide tuning range.

While the PIN diodes, FETs, and varactors are used as tunable devices in microwave systems, the ferroelectrics such as a BST ($Ba_xSr_{1-x}TiO_3$) and a STO ($SrTiO_3$) can be new candidates for tunable devices in millimeter-wave and sub-millimeter-wave devices with low loss, light weight, and small size. Also, tunable BST devices can be used in microwave components for wireless communication systems.

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