Tunable microwave integrated circuits using BST Thin Film Capacitors with 
Device Structure Optimization

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Abstract:
Ba$_x$Sr$_{1-x}$TiO$_3$ (BST) thin films have been investigated for microwave circuit application 
because of their high dielectric constants, high tunability, relatively low loss, and fast switching 
speed. Recently, tunability of BST film was reported as high as 13:1 [1]. It makes BST film 
technology attractive to low cost agile microwave circuits, such as phase shifters, tunable filters, 
tunable matching network and high tuning frequency range VCO. Additionally, due to its high 
dielectric constant, BST is a candidate for very compact MMIC DC blocking capacitors, 
promising a 100-fold reduction in capacitor area as compared with SiN and SiO$_2$ capacitors.

Most pervious works covered material quality, choice of electrodes and processing techniques. 
Less effort has been put on advanced device designs, leaving room for further improvement. 
Quality factor, resonate frequency and breakdown voltage are major factors, which determine 
applications of BST capacitor in MMIC. The loss of high frequency device was consisted of the 
loss of material in the film and at interface and the resistive lose on electrodes. Here we present 
an improved structure (Fig. 1) with a dielectric pad under the cross-over bridge. With this 
structure, the thickness of both top and bottom electrodes can be increased to further reduce the 
resistive lose. Also it can avoid the premature breakdown at the edge of bottom electrode under 
the cross-over. We study the high frequency properties of BST thin film capacitors with different 
peripheries. By varying W/L aspect ratio of devices, an optimized Q factor can be achieved 
within a reasonable W/L aspect ratio range. As shown in Fig. 2, this will help to improve the 
peak performance of integrated circuits. A lumped RF model was used to simulate the 
relationship between Q factor and aspect ratio and help to optimized periphery structure.

Several tunable MMICs were designed and fabricated using individually optimized high 
frequency BST capacitors. Fig. 3(a) shows a 2.4-3.6 GHz 1st order tunable band pass filter with 
1.6 dB insert loss. The parallel inductance was implemented by a CPW short stub. Fig. 3(b) 
shows a 2-4 GHz tunable lumped-element-based 3rd order band pass filter with 9dB insert loss. 
Fig. 3(c) demonstrates a 10-15 GHz lumped-element-based 3rd order low pass filter. The LPF 
exhibited an insertion loss of 0.1 dB. The maximum tuning bias voltages for all above circuits 
were within 20 V range. Fig.3 (d) represents an electric oscillator with BST capacitors as 
compact DC blocking capacitors. We developed a valid method of integration BST film in active 
GaN HEMT circuit [2]. The oscillator, based on AlGaN/GaN HEMT, delivers 20.7 dBm output 
power at 5 GHz with phase noise of -105 dBc/Hz at 100 kHz offset.

Reference::
“Integration of BaSr$_{1-x}$TiO$_3$ thin films with AlGaN/GaN HEMT circuits,” IEEE Electron Device 

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Figure 1. (a) Top view and (b) cross-section view of high frequency BST capacitor structure.

Figure 2. (a) Measured and (b) simulated Q factors of high frequency BST capacitors with different capacitances and aspect ratios at 3 GHz.

Figure 3. BST technology based MMICs. (a) 1st order tunable BPF. (b) 1st order tunable BPF. (c) 3rd order tunable LPF. (d) GaN HEMT oscillator using BST DC blocking capacitors.