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A Novel K-Band Tunable Microstrip Bandpass Filter Using a Thin Film HTS/Ferroelectric/Dielectric Multilayer Configuration

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A NOVEL K-BAND TUNABLE MICROSTRIP BANDPASS FILTER USING A THIN FILM HTS/FERROELECTRIC/DIELECTRIC MULTILAYER CONFIGURATION

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ABSTRACT

We report on YBCO/strontium titanate (STO) thin film K-band tunable bandpass filters on lanthanum aluminate substrates. The 2 pole filters were designed for a center frequency of 19 GHz and 4% bandwidth. Tunability is achieved through the non-linear dc electric field dependence of the relative dielectric constant of STO(ε_{rSTO}). Center frequency shifts of greater than 2 GHz were obtained at a 400V bipolar dc bias at temperatures below 77K, with minimal degradation in the insertion loss of the filters.

INTRODUCTION

The non-linear dc electric field dependence of strontium titanate (STO) ferroelectric thin film's relative dielectric constant (ε_{rSTO}) has been studied in recent years because of their potential application in tunable microwave components such as varactors, phase shifters, resonators, and filters [1-3]. It has been demonstrated that ε_{rSTO} could be reduced by more than a factor of 5 under the influence of a dc electric field below 100K [2]. A YBCO/STO/ Lanthanum aluminate($LaAlO_3$) coplanar bandpass filter designed for 2.5 GHz has been demonstrated by Findikoglu et al., [3]. Large tunability (~15%) and improved filter performance resulted from the applied dc field. However, it remained to be seen if similar results can be obtained at considerably higher frequencies, where size reduction could hinder the optimum performance of these filters. In this paper, we report on a novel 19 GHz, 2 pole tunable YBCO/ STO microstrip bandpass filter on $LaAlO_3$ substrate. The experimental performance of this filter demonstrates the feasibility of this technology for applications in K-band satellite communication subsystems such as a receiver front-end.

DESIGN

The 2 pole bandpass filter was designed using the microstrip edge coupled half wavelength resonators. The filter was designed for a center frequency of 19 GHz, with 4% bandwidth, and the passband ripple below 0.5 dB. The cross-section of the multilayered microstrip structure is shown in figure 1. The multilayered microstrip structure consists of a $LaAlO_3$ substrate (254 μm thick), 0.30 μm thin film STO layer, and a 0.35 μm YBCO thin film for the microstrip, and 2 μm thick gold ground plane. The optimal design was achieved using Sonnet em® analysis CAE package. The geometry of the optimized filter circuit is shown in figure 2. The

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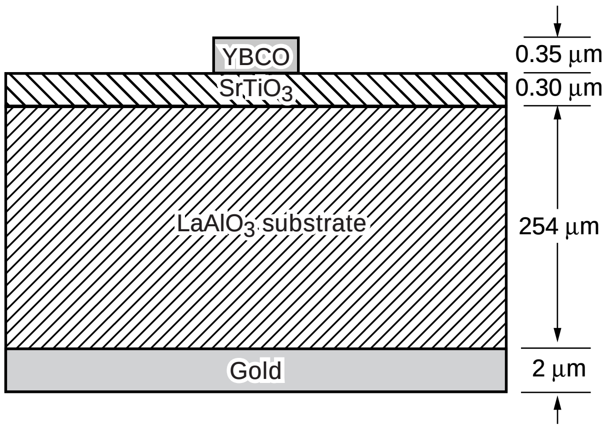

Figure 1.—Cross-section of the multilayered microstrip structure used for the tunable filters.

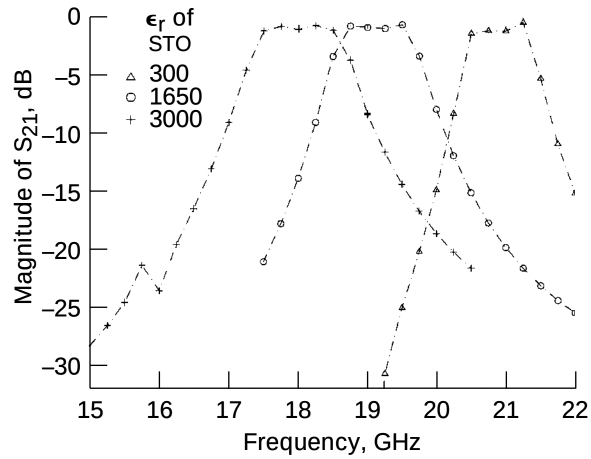

Figure 3.—Theoretical simulation results for the bandpass filter using sonnet em®.

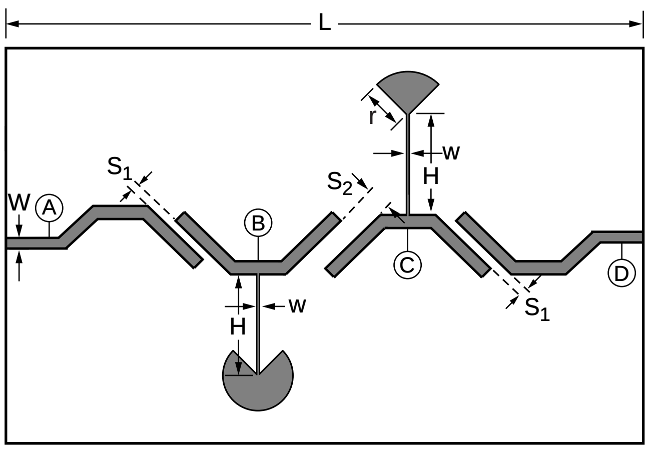

Figure 2.—The geometry of the optimized tunable filter circuit. The dimensions are: W = 86.25 µm, L = 6.8 mm, S_1 = 100 µm, S_2 = 300 µm, H = 1.33 mm, w = 12.5 µm, and r = 200 µm.

Sonnet em® simulation results for the YBCO/STO/$LaAlO_3$ multilayered microstrip bandpass filter are shown in figure 3, for the cases of ε_{rSTO} equal to 300, 1650 and 3000. The filter's insertion loss at 77K was near 0.7 dB in the worst case, and barely changed as the ε_{rSTO} was varied from 300 to 3000. The filter was designed such that its normal operation corresponds to ε_{rSTO} of 1650, which as shown in figure 3 results in a center frequency near 19 GHz. The implication of this is the need to maintain a suitable bias for the normal operation of the filter. As shown in figure 3, the center frequency of the circuit shifts from 17.75 GHz to 20.75 GHz, a tunability factor greater than 15%, with no appreciable change in the insertion loss. The return loss in the passband was better than 20 dB for all the three cases.

EXPERIMENTAL

The YBCO/STO/$LaAlO_3$ samples used in this study were bought from Superconductor Core Technologies(SCT), Golden, Colorado. Both the superconducting and the ferroelectric films were deposited by laser ablation. The deposition and post annealing techniques for the STO and YBCO thin films have been thoroughly discussed previously [2]. The microstrip bandpass filter circuit was fabricated at SCT using a dry chemical etching technique [2]. A 2 µm gold ground plane was deposited to complete the circuit fabrication. The circuits were packaged for testing of the filter's swept frequency S-parameters in a helium gas closed cycle cryogenic system. The tunability of the circuit was studied with a dual polarity biasing technique. Referring back to figure 1, the nodes A and C were connected to the positive bias, and the nodes B and D were connected to a negative bias of same magnitude. The nodes A and D were biased using input and output bias tees. The biasing at nodes B and C were achieved using gold wire bonds on the radial biasing stubs. The DC bias was increased from 0V to ±500V in steps of ±50 V. The maximum electric field applied does not exceed 10^5 V/cm.

RESULTS AND DISCUSSIONS

The field dependence of one of the filter's S_{21} and S_{11} are shown in figure 4, at 77K, measured at an input power level of +10 dBm. With increasing bias voltage, the center frequency of the filter shifted from 17.4 GHz at no bias to 19.1 GHz at ±500V bias, giving a tunability factor of 9%. With applied bias, both S_{11} and S_{21} improved as shown in the figure. Another filter exhibited superior tunability at 30K, as shown in figure 5. The center frequency of the circuit shifted from 16.5 GHz at no bias, to 18.8 GHz at ±400V bias, indicating a tunability factor greater than 12% at 30K. Note that in figure 5, the passband insertion losses did not change appreciably throughout the tuning range of the filter. The non-deembedded insertion losses of these proof-of-concept filters were within a factor of 3, of that predicted by the theoretical simulation (~0.7 dB). For the filter in figure 4, the lowest passband insertion loss measured was ~1.5 dB at 24K. In general, the return losses S_{11} and S_{22} were near or better than 10 dB in the passband for the circuits tested. The unloaded Q of the filters was estimated to be approximately 200 using the expression $Q = 8.686\, C_N\, \omega_1'/(\omega\, \Delta L)$ where ω_1' is the lower pass prototype cutoff frequency (normally = 1), ω is the percentage bandwidth, ΔL is the minimum insertion loss in dB, and C_N is a constant which depends on the order of the filter [4]. Optimization of the HTS and ferroelectric films to obtain lower insertion losses and better tunability near 77K and lower bias voltages are currently underway.

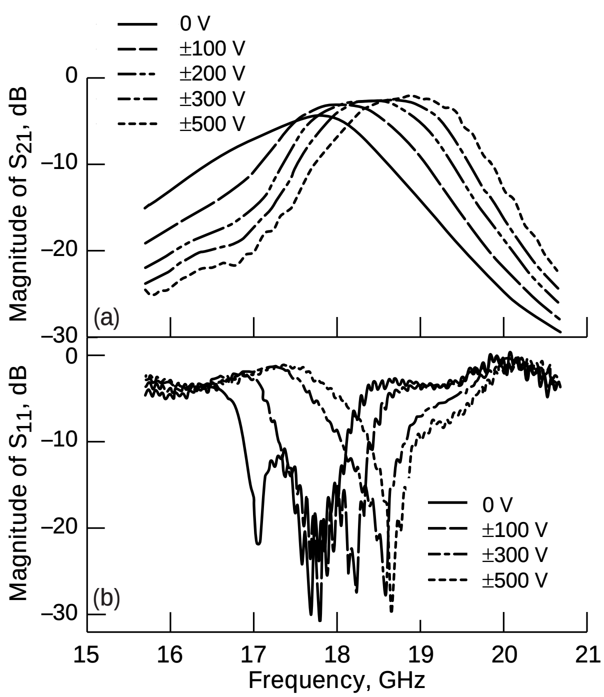

Figure 4.—Field dependence of S_{21} and S_{11} for a tunable bandpass filter at 77 K.

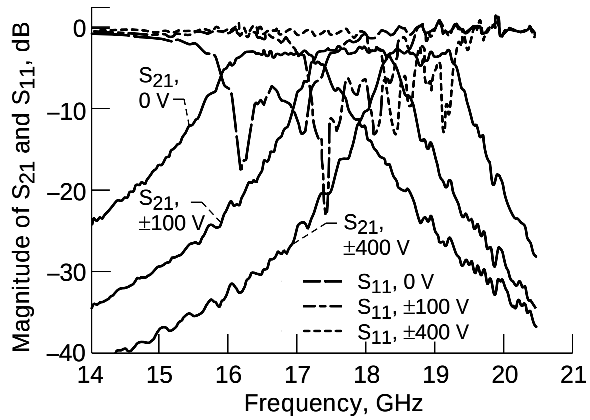

Figure 5.—The bias dependence of S_{21} and S_{11} for a tunable bandpass filter at 30 K.

SUMMARY AND CONCLUSIONS

In summary, a planar tunable microstrip bandpass filter with low insertion loss, has been designed and realized using a YBCO thin film and a non-linear dielectric STO ferroelectric thin film. Experimental results indicated 12% and 9% tunability at 30K and 77K, respectively, using the electric field dependence of the ε_{rSTO}. Our results prove the feasibility of using tunable HTS/ferroelectric thin film planar microstrip circuits at K-band frequencies.

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