THIN-FILM RESONATOR LADDER FILTER

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Abstract

Thin-film bulk acoustic wave resonator (BAWR) ladder filters have been realized with IL ~ 2.2 dB, and selectivity ~ 15 dB for a three resonator filter, IL ~ 5 dB and selectivity ~ 32 dB for a five resonator filter. Filters with seven and nine resonators have also been characterized. This performance corresponds to achieving a figure of merit Q/r ~ 10. The performance possibilities of ladder filters have been calculated with the Q/r figure of merit as a parameter. It is anticipated with improvements in processing and device designs, AlN or ZnO thin-film BAWR ladder filters should achieve IL ~ 1.5 dB and selectivity ~ 40 dB, corresponding to Q/r ~ 40 at 1.5 GHz.

Introduction

There has been a lot of interest in thin-film resonator filters because of their small size and light weight, potential good performance, and integration into monolithic integrated circuits. In the last few years there have been papers [1-4] that discuss various filter implementations, including stacked crystal filters, monolithic filters, and ladder filters. The stacked crystal filters are difficult to process and expensive because they require two layers of piezoelectric films. The monolithic filters require very precise spacing to control the acoustic coupling of the resonators. Moreover, the coupling might not be enough to realize filters with sufficient bandwidth for general wireless communications. The ladder filters do not have these fabrication limitations. However, published results to date have not shown the good performance expected of ladder filters.

Ladder filter figure of merit

There are several common metrics used to characterize piezoelectric materials and resonators. While these have been useful in comparing the relative merits of materials [5, 6], or the ultimate frequency of possible application and technology directions [6], the metrics have not been explicitly related to ladder filter performance. The maximum achievable fractional bandwidth of a thin-film resonator filter is given by the "crystal bandwidth" 1/(2r) [7, 8] , where r is defined to be the ratio of the static capacitance to the motional capacitance of the resonator. The other filter characteristics of interest, the insertion loss and the selectivity of a ladder filter, are related to the figure of merit Q/r ratio. Q is the quality factor of the resonator. Here selectivity is defined as the difference in dB between the minimum insertion loss of the designed passband and the minimum rejection away from the passband. The harmonic and spurious mode passbands are neglected as they are usually far enough away from the frequency of interest. By using a Butterworth-Van-Dyke (BVD) model of a resonator, selectivity versus insertion loss of a ladder filter can be generated as a function of the parameter Q/r. Since surface acoustic wave resonators (SAWR) have similar BVD models, such a relationship applies to these ladder filters as well.

Results

We have recently fabricated on-wafer probeable ZnO thin-film ladder filters with three to nine resonators. The resonators are on both the series and shunt arms of the filter circuit. The filters have I/O ports matched to 50 ohms. The bandpass characteristics are plotted in fig. 1 and fig. 2. On the same wafers we have also fabricated single resonators similar to those used in the filters. By mathematically manipulating the single resonator data files, we have simulated the ladder filter responses shown in fig. 3 and fig. 4. The simulations approximate the realized responses quite well, verifying the succesful ladder filter fabrication process. Simulations of the seven and nine resonator filters deviated from the characterized filters. This is due to leakage through the semiconductive dielectric underneath the resonators and a flaw in the layout of the seven resonator filter. The insertion loss and selectivity of these realized filters are plotted in fig. 5 together with the predicted performance of ladder filters as a function of Q/r. Typical measured performance of SAWR ladder filters fabricated on lithium niobate crystalline substrates are also plotted in Fig. 5 for comparison. Separate materials characterization efforts indicate that thin-film bulk acoustic resonators with Q/r ratio as high as 40 should be attainable at 1.5 GHz for both ZnO and AlN material systems.

Conclusion

Some recent ZnO thin-film bulk acoustic wave resonator filter results have been reported. These results are similar to the AlN filters reported in [3]. Based on the materials constants of the commonly used piezoelectric thin-films, it is estimated that the ladder filter performance can be improved to specifications commonly used for wireless communications equipment, reaching a ladder filter figure of merit Q/r ~ 40.

Acknowledgements

We acknowledge Dr. Larry Dworsky's critical review of the paper and his posing of the question for performance limits of ladder filters. We also acknowledge Materials Research and Strategic Technologies, and Phoenix Corporate Research Laboratories personnel for processing and testing the filters.

References

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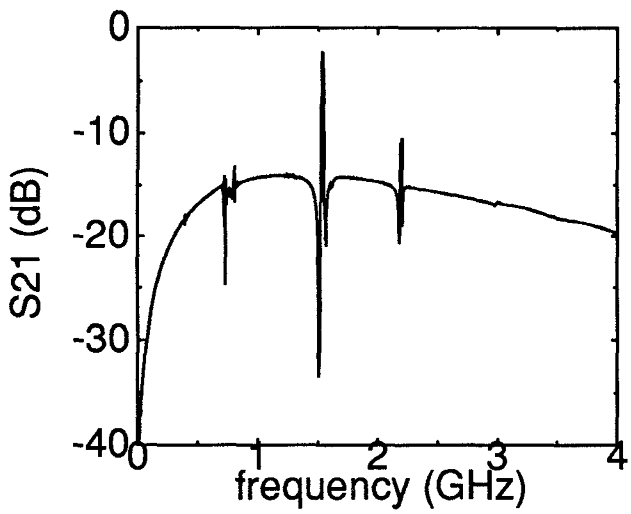

Fig. 1a 3 resonator thin-film BAWR filter

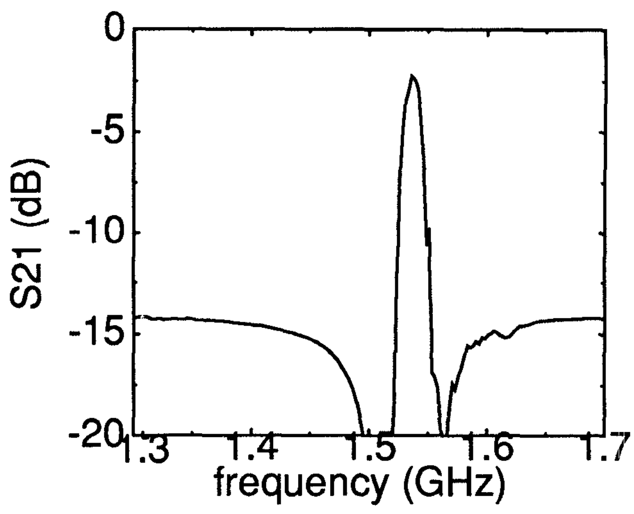

Fig. 1b close-in 3 resonator filter response

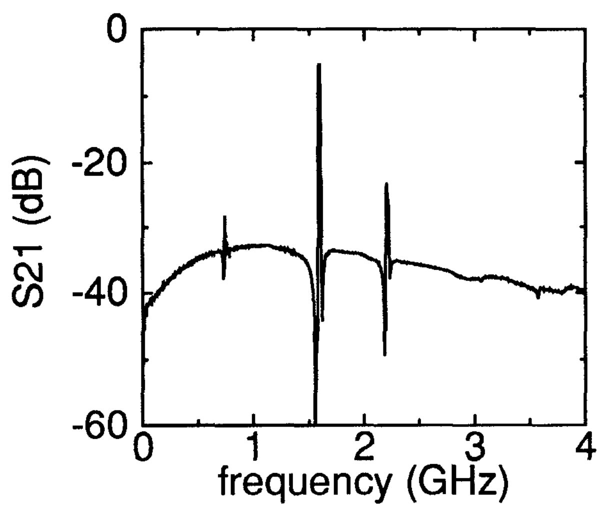

Fig. 2a 5 resonator thin-film BAWR filter

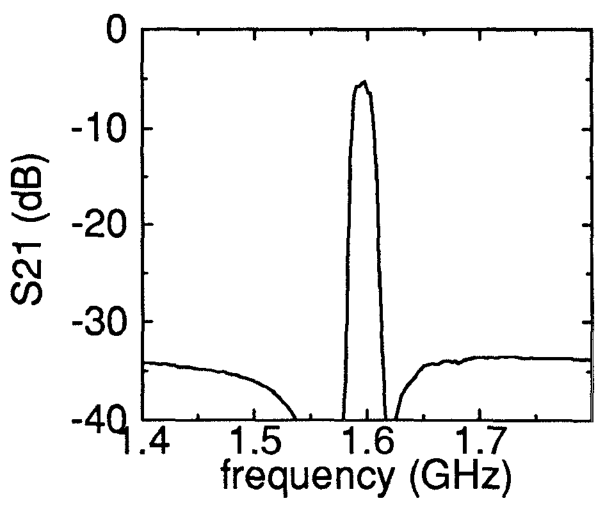

Fig. 2b close-in 5 resonator filter response

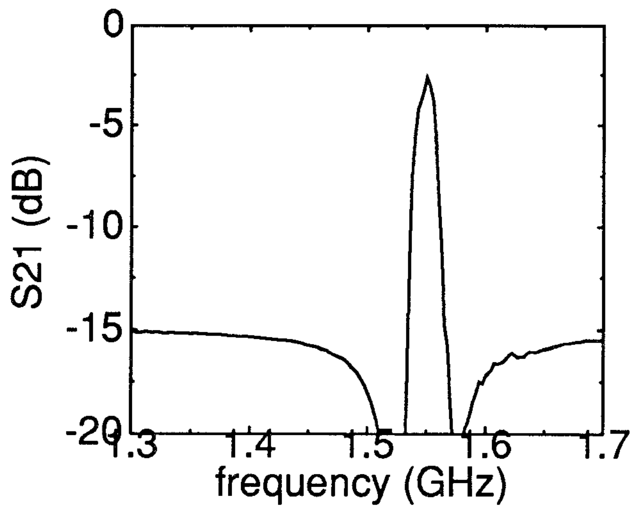

Fig. 3 Simulated 3 resonator ladder filter

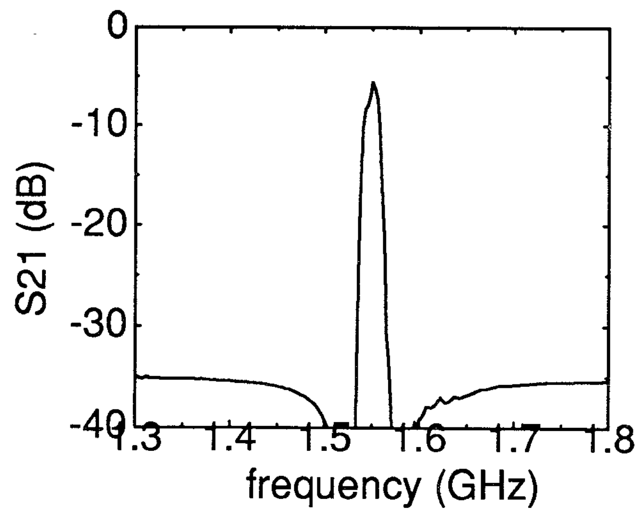

Fig. 4 Simulated 5 resonator ladder filter

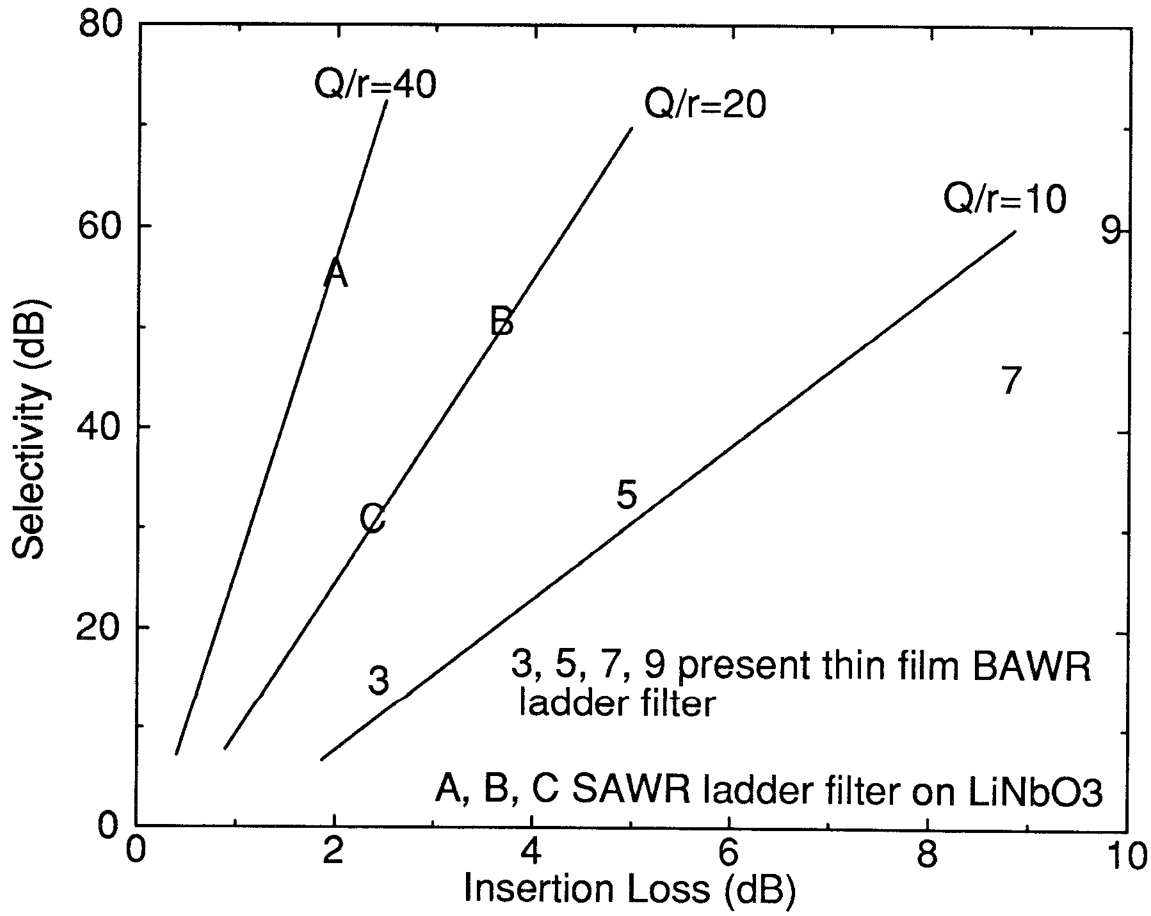

Fig. 5 Selectivity versus Insertion loss of piezoelectric resonator ladder filters