MULTILAYER TUNABLE FERROELECTRIC HIGH-Q FILTERS

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***ABSTRACT* — This paper presents novel multilayer tuneable high Q-filters based on hairpin resonators including ferroelectric materials. This configuration allows the miniaturization of these filters to a size that makes it suitable for chip & package integration and narrow band applications. The multilayer structure allows for high Q by supporting a dielectric mode instead of a conductor transmission line mode. Different configurations of band reject filters are presented to illustrate the benefits of the present design.**

***Index Terms* — Ferroelectric materials, Microstrip filters, Hairpin resonators.**

I. INTRODUCTION

Filters and oscillators account for a significant portion of wireless device cost and size. Therefore, integration of filters is highly desirable. Derived from edge coupled line filters, Hairpin-line filters [1-2] are known for their compact size (half the size of coupled line filters) and design simplicity. However, even with 2:1 size reduction, X-band is probably the most common application of these filters. Their size is still large for integrated wireless applications. Filter tuning remains a challenge due to the large size. Hairpin filter developments have been focused primarily on high temperature superconductors (HTS) [3-4] where conductor losses of no concern. This further limits the applications of hairpins for mobile applications. Weak coupling between hairpin resonators makes it simpler to analyze [3], [5] but results in high insertion loss and increased spacing between resonators which increases the overall filter size.

The progress and feasibility of filter integration is usually coupled to filter tuning. Electronic tuning is used to compensate for manufacturing and process variations. Ferroelectric materials have been suggested for both filter tuning and size reduction [6-9]. Most ferroelectric materials have relative dielectric constant greater than 200. There is a trade-off between material Q and tunability. Materials like $KTaO_3$ have high Q, greater than 10,000, but have poor tunability of less that 1% per V/μm. The preferred choice has been $BaSrTiO_3$ which has a relative dielectric constant equal or greater than 5000 and tunability of 20% per V/μm but has a poor Q of less than 100. The most common design is the lumped element filter with ferroelectric loaded capacitors [9]. This approach yields a low Q of less than 30 due to the low Q of the lumped elements.

This paper describes the properties of a multilayer dielectric mode filter coupled through hairpins to increase coupling and reduce size. Tight coupling is required to achieve low insertion loss. Medium k and high Q material, such as $KTaO_3$, is inserted between two layers of high k material such as $BaSrTiO_3$. The high k material pulls the fields inside the low k material to enhance both tunability and Q. The present modes are EM dielectric modes in the ferroelectric material for the design of band-reject filter and oscillator applications.

II. DIELECTRIC MODE HAIRPIN FILTERS

Simple band reject filters (BRF) can be constructed using a D. R. placed next to a microstrip line as shown in Fig. 1.

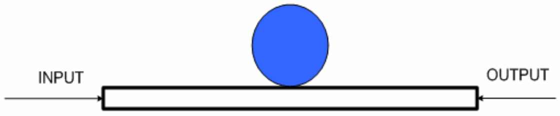

Fig. 1: Conventional dielectric resonators.

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This dielectric mode filter has a Q on the order of 5000 [10]. It is attempted to couple ferroelectric bars made of $KTaO_3$ (with a relative dielectric constant of 240 and Q of about 10,000) to a 50 ohms microstrip line as shown in Fig. 2.

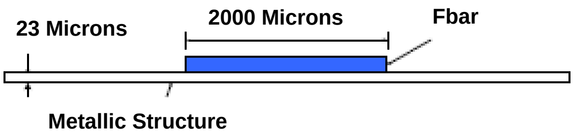

Fig. 2: FBAR coupled to a microstrip line.

The present dimensions of the microstrip and ferroelectric bar are required for on-chip integration.

In order to increase the coupling and to enhance the filter characteristics, a hairpin is wrapped around the ferroelectric bar as shown in Fig. 3.

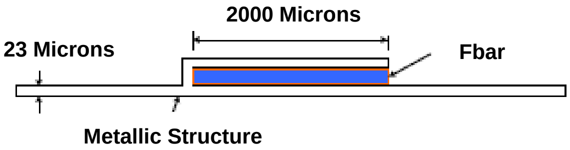

Fig. 3: FBAR coupled to a microstrip hairpin with side coupling.

Next, the hairpin is coupled to the 50 ohms line at an edge of the hairpin as shown in Fig. 4.

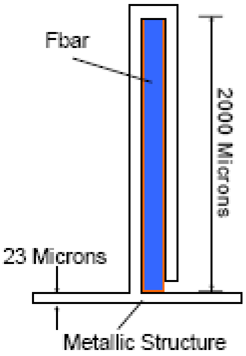

Fig. 4: FBAR coupled to a hairpin with edge coupling

III. MULTILAYER FILTERS

The material, which is used in the above described devices as ferroelectric bars made of $KTaO_3$ (with a relative dielectric constant of 240 and Q of about 10,000), and it has a very poor tuning, but fairly high Q. In order to increase the tunability, another material, namely a BaSrTiO3 layer can be used in conjunction with $KTaO_3$ as shown in Fig. 5. Thus, multilayer filter structures may be obtained.

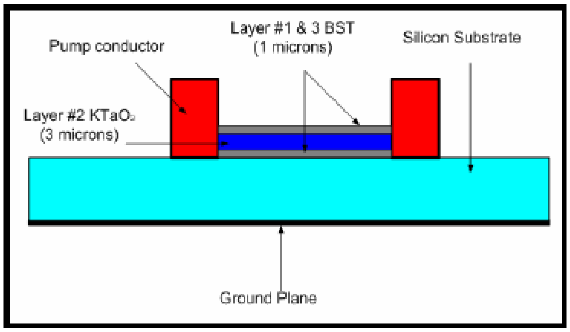

Fig. 5: Geometry of a multilayer BRF.

IV. RESULTS AND DISCUSSION

The performance of the filter depicted in Fig. 2 is calculated versus frequency using the HFSS software package from Ansoft and is shown in Fig. 6.

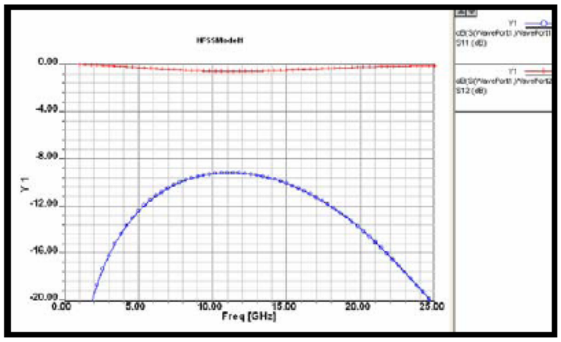

Fig. 6: Frequency response of an FBAR coupled to Microstrip line.

The computed results show poor coupling at 10 GHz for a 2000 micron bar. A significant improvement in coupling and Q, as compared to the simple bar (see hereto Fig. 3), is observed as shown in Fig. 7.

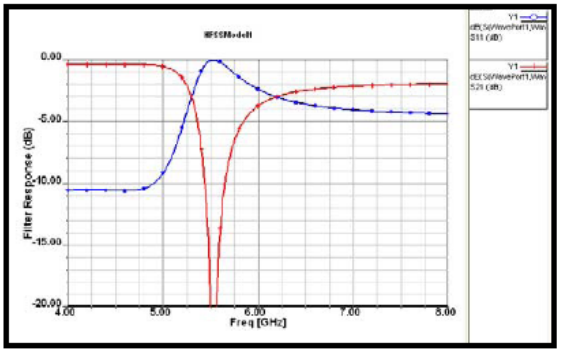

Fig. 7: Frequency response of an FBAR coupled to a microstrip hairpin with side coupling.

Also the resonant frequency is reduced by a factor of 2 for the same bar dimension. When the field distribution is studied, it has been found that the loop of the hairpin produces a maximum magnetic field in the ferroelectric bar resulting in effectively a virtual ground at the loop. A maximum electric field occurs at the open end. Thus, the dimension of the resonant bar is reduced to λ/4 instead of λ/2 as compared to case given in Fig. 2. To verify the type of mode, the hairpin is coupled to the 50 ohms line at an edge of the hairpin as shown in Fig. 4. The resonant frequency did not change significantly, as shown in Fig. 8.

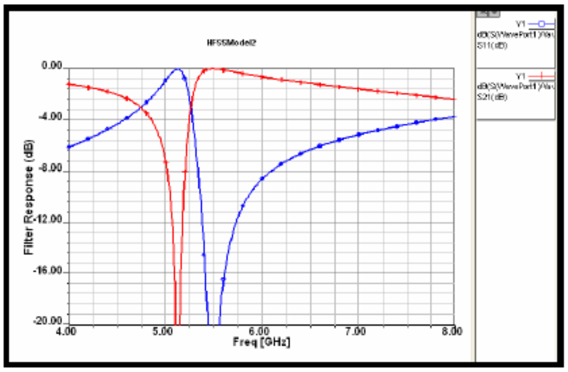

Fig. 8: Frequency response of an FBAR coupled to a hairpinwith edge coupling.

Then, the resonant frequency of a similar hairpin without the ferroelectric material is studied. The response of the conductor transmission line mode shifts by a factor of 2:1. To demonstrate this behavior and show the effectiveness of hairpin coupling to dielectric resonant modes, two cases were simulated without the dielectric bars.

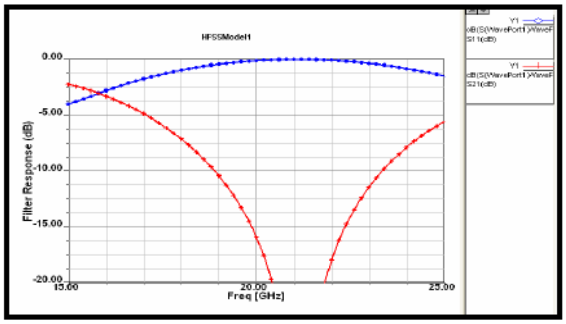

Fig. 9: Frequency response of a conductor hairpin with side coupling.

When the hairpin excitation is shifted from the side (Fig. 9) to the edge (Fig. 10), the resonant frequency decreased as expected by a factor of 2:1, as predicted. Simulation results also show a lower Q than dielectric modes by at least a factor of 10. The use of high dielectric materials also reduced the resonant frequencies by a factor of 4 without sacrificing Q. The values of Q have improved from about 10 in the case of conductor hairpins, and up to 100 in the case of ferroelectric material including conductor loss (bump copper conductor is assumed).

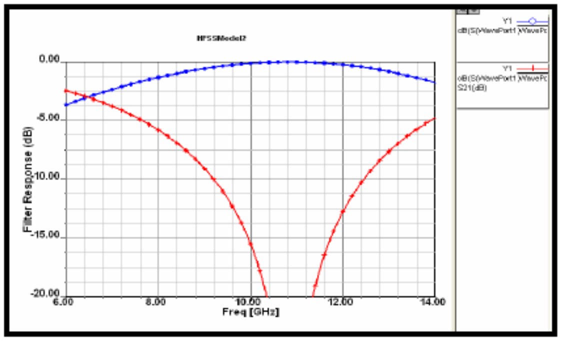

Fig. 10: Frequency response of a conductor hairpin with edge coupling

In all simulations, a silicon dioxide substrate was used with an effective dielectric constant of 4 and a thickness of 15 μm which gives a 50-ohms microstrip line of 23 μm width. The conductor thickness is set to 10 μm. Ferroelectric bars width and thickness is optimized to give a high Q.

Fig. 11 shows the response of a multilayer filter depicted in Fig. 5. Here, the same hairpin as shown in Fig. 4 with 2μm thick $BaSrTiO_3$ is used.

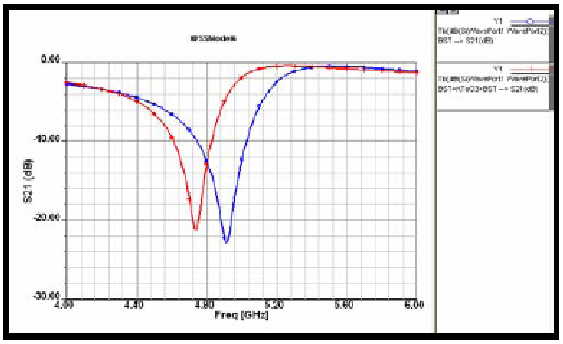

Fig. 11: Frequency response of a multilayer structure

This picture also shows the new response when a 3 micron $KTaO_3$ is inserted in the middle of the $BaSrTiO_3$ layer. The figure indicates an improvement in Q of up to 20 %. The resonant frequency shifted downward as expected.

Finally, the tunability of the multilayer structure is tested by applying a DC voltage between the hairpin and the ground plane of the microstrip line.

Fig. 10: Frequency response of a multilayer structure

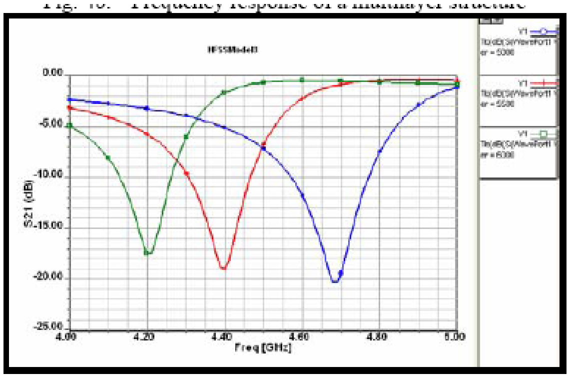

Fig. 12: Frequency response (S21 (dB)) – of tunable multilayer structure.

A decent tunability in the order of 5% is predicted for a 20 Volts variation in the DC voltage as shown in Fig. 12.

V. CONCLUSION

In this paper, integration of passive filters on silicon substrates is investigated. Simple hairpin band reject filters (BRF) that support dielectric mode is presented. Ferroelectric bars were used as resonant elements, compared to transmission line hairpin resonators; an improvement of about 10 in Q is achieved. Multilayer dielectric ferroelectric material is discussed and gives about 5% tunability.

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