Resonator Size Effects on the TFBAR Ladder Filter Performance

Kun-Wook Kim, *Student Member, IEEE*, Myeong-Gweon Gu, Jong-Gwan Yook, *Member, IEEE*, and Han-Kyu Park, *Senior Member, IEEE*

***Abstract*—Thin-film bulk acoustic resonators with different resonator sizes are simulated and measured. Their effects on ladder filter performance are also presented. Aluminum nitride and platinum are used as piezoelectric material and electrodes, respectively. As the shunt resonator size increases, out-of-band rejection performance has been improved. The 3/2 stage filters that have twice or three times larger resonators reveal 6 dB and 11 dB out-of-band rejection improvements, respectively.**

***Index Terms*—Ladder, resonator size effect, RF MEMS, TFBAR filter.**

I. Introduction

VARIOUS breakthroughs in the integration process have enabled the miniaturization of RF handheld transceiver systems. Because most RF front-end handheld transceiver systems require a number of RF and IF bandpass filters for band selection or image rejection, the miniaturization and integration on-chip of these bandpass filters are upcoming issues. Current RF front-end systems operating in GHz region utilize ceramic or surface acoustic wave (SAW) filters for frequency selective devices. However, these ceramic and SAW filters pose inherent difficulty in the implementation of miniaturized on-chip systems, and they also have poor electrical power handling capability as well as limited frequency range characteristics [1]. Given the above observations, TFBAR-based filter is one of the promising alternatives, since it is a silicon-compatible integrated solution for miniaturized filters and overcomes the difficulties described above [1], [2].

TFBAR is composed of thin film piezoelectric materials, such as aluminum nitride (AlN), zinc oxide (ZnO), or lead-zirconium-titanate (PZT), sandwiched between top and bottom electrodes. In recent research, TFBARs with various piezoelectric material have been proposed which are suitable for mobile communication RF bandpass filters around $1 \sim 2$ GHz region [3]–[7]. In ladder topology, the resonant frequency of shunt TFBARs should be adjusted $2 \sim 3\%$ lower than that of the series TFBARs, which can be accomplished by controlling the thickness of the top electrode.

Mason model [8] is the most widely used in the behavioral analysis of piezoelectric materials; however, Mason model can be simplified to Butterworth-Van Dyke (BVD) model with some assumptions. Larson [4] added the material loss term to the conventional BVD model and named MBVD model which is used in this letter. Further, Lakin [3] and Larson [4] reported on the analysis and tuning methods of solidly mounted resonator(SMR) type filters for cellular and PCS applications and Ruby [5] reported on TFBAR-based PCS duplexers. Su [6] analyzed the effects on the resonator performance of the thickness and area size of the edge-supported type ZnO and PZT TFBARs, however, the effects of resonator size on the filter performances are not reported.

In conventional ladder type filters, the resonator size is fixed and the number of stages is increased to achieve specification requirements such as out-of-band rejection. Enlarging the shunt resonator size enables the out-of-band rejection improvements with equal number of stages and without changing the resonant frequency. In this letter, the effects of double-sized as well as triple-sized shunt resonators are analyzed for 3/2 stage filters.

II. Modeling of Single TFBAR

TFBAR can be classified into three types; air-gap type, back-etched type and solidly mounted type. The air-gap type TFBAR has apparent advantages in the fabrication aspect compared with other types. The latter two types require rather complex fabrication procedures, because the substrate material must be etched away or several layers of different materials must be carefully stacked on silicon substrate. Geometry of air-gap type TFBAR and its electrical model are shown in Fig. 1. Modified Butterworth-Van Dyke model (MBVD) is proven to be very useful in parameter extraction from measure data. While the original Butterworth-Van Dyke model is composed of five passive components, L_m, C_m, R_m, C_0, and R_S, the MBVD has another resistive element R_0 describing material loss. The equivalent circuit elements are given as follows as a function of material parameters:

$$C_0 = \frac{\epsilon_r \epsilon_0 A}{d} \quad (1)$$

$$R_m = \frac{\pi \eta \epsilon_r \epsilon_0}{8 k_t^2 \rho A \omega v_a} \quad (2)$$

$$C_m = \frac{8}{\pi^2} k_t^2 C_0 \quad (3)$$

$$L_m = \frac{\pi^3 v_a}{8 \epsilon_r \epsilon_0 A \omega^3 k_t^2} \quad (4)$$

$$\omega^2 = \frac{1}{L_m C_m} \quad (5)$$

where ϵ_r is relative permittivity of piezoelectric material, ϵ_0 is permittivity of free space, η is acoustic viscosity, ρ is density,

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K.-W. Kim, J.-G. Yook, and H.-K. Park are with the Department of Electrical and Electric Engineering, Yonsei University, Seoul 120-749, Korea (e-mail: kwkimys@yonsei.ac.kr; jgyook@yonsei.ac.kr).

M.-G. Gu is with the MEMS Solutions, Inc., Seoul 120-749, Korea.

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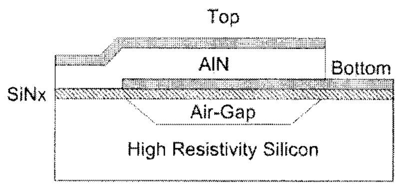

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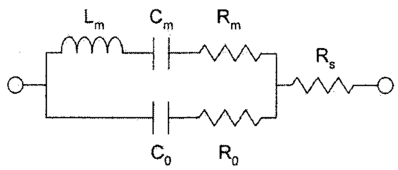

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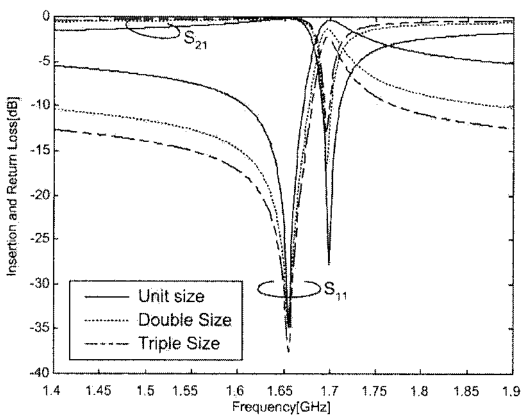
Fig. 1. Geometry and MBVD model of TFBAR. (a) Geometry and (b) MBVD model.



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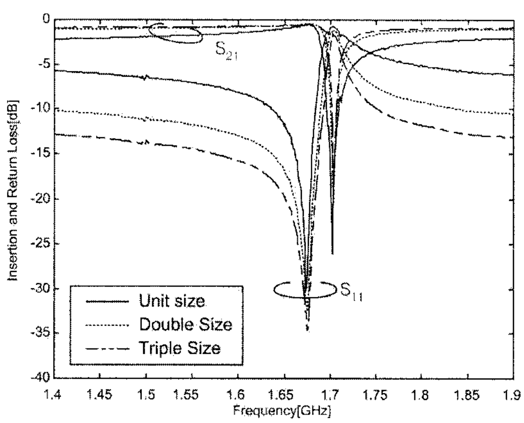
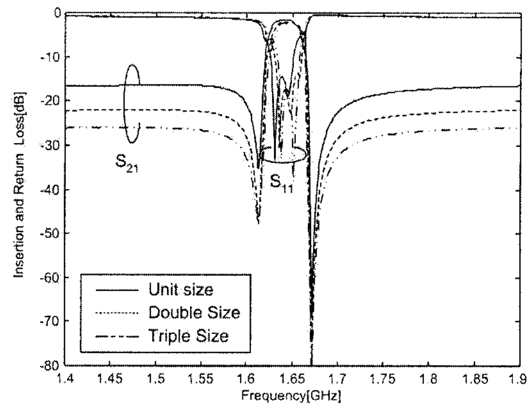


(b)

Fig. 2. Frequency responses for different resonator size. (a) Simulation and (b) measurement.

v_a is acoustic velocity, A is resonator size, k_t^2 is piezoelectric coupling constant and ω is series resonant frequency. The unit resonator size of $150 \times 150\ \mu\mathrm{m}^2$ is used in this letter. Since all of the material constants are extracted from measured data, the modeling parameters are obtained from (1)~(5). The extracted MBVD model parameters of single resonator with unit size are; C_0 of 2.3 pF, C_m of 57.2 fF, L_m of 158 nH, R_m of 1.5 Ω , R_0 of 0.98 Ω , R_s of 2.06 Ω, respectively. Q value of the resonator is around 1000 and k_t^2 is around 4.5%.



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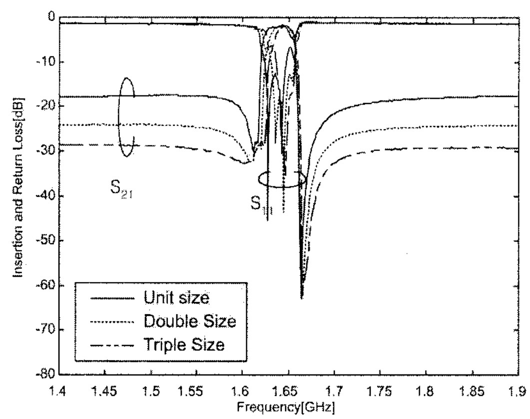

(b)

Fig. 3. Frequency response with respect to shunt resonator size. (a) Simulation and (b) measurement.

Fig. 2 shows the frequency response of TFBAR with different sizes. As the resonator size becomes larger, the return loss as well as the insertion loss of the resonator exhibit quite different characteristics while maintaining the same resonant and anti-resonant frequencies. There is very little change in resonant frequency, because as the area of TFBAR increases, the electrical and mechanical capacitances increase in a similar fashion but the mechanical inductance decreases.

III. Filter Design and Results

Through the basic theory in previous section, the ladder filters connecting series and shunt TFBARs are constructed. The frequency response of the bandpass filter is obtained by multiplying the ABCD parameters of each stage and convert them to S parameters. The resonant frequency of the shunt TFBAR should be adjusted $2 \sim 3\%$ lower than that of the series TFBARs, which is accomplished by changing the thickness of the top electrode.

As the area of shunt resonator increases, as shown in Fig. 3, it is apparent that the out-of-band rejection is significantly improved while maintaining the same bandwidth characteristics. If number of stages or resonators increased, one could obtain the similar characteristics, however, total dimension of the filter may increase. As the shunt resonator size increases, sideband suppression improvement of about 6 dB is achieved with double-sized shunt resonators, and 11 dB improvement with triple-sized shunt resonators without changing resonant frequency and bandwidth performance.

IV. Conclusion

In this letter, TFBAR ladder filter characteristics with different series and shunt resonator size are reported. Aluminum nitride is used as piezoelectric material and platinum is used as top and bottom electrodes. In 3/2 stage ladder bandpass filter, the increase of the series resonator size degrades out-of-band rejection characteristics, however that of the shunt resonator size enables 6 dB and 11 dB improvement for double-sized resonator and for triple-sized resonator, respectively.

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