Optimization of BAW Resonator for Wireless Applications using Taguchi's Orthogonal Array Method

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Abstract: BAW (Bulk Acoustic Wave) resonators are rapidly growing highly integrated devices with wide range of applications in wireless domains. Fabrication of thin film BAW resonators are highly challenging over material selections and measures of materials. RF properties of BAW resonators depending on the device parameters are simulated for their performance using COMSOL Multiphysics tool. In our study the measures of highly effective control parameters of resonator are actively optimized using Taguchi's orthogonal array method. This study is quite competitive and is a tool for designers in selecting device parameters with required quality factor for futuristic wireless applications and is cost effective.

Keywords: BAW resonators, acoustic thin films, Comsol Simulation, Orthogonal arrays, Optimization,

1. Introduction

BAW has several advantages as they are remarkably small in size, have better power handling abilities and better temperature coefficients leading to more stable operation and hence preferred over SAW. From a practical point of view SAW filters have considerable drawbacks beyond 2 GHz whereas BAW devices up to 16 GHz have been demonstrated [1]. Due to good selectivity and steep transition band offered for cellular applications, modelling and development of *high Q* thin-film BAW devices is a topic of research gaining attention [2]. Transmit and receive bands of the US-PCS standard are close in frequency in the commercially available for US-PCS (1.85GHz-1.91 GHz) applications. These applications need nearly lossless high Q resonators for RF filters [3-6]. The resonator is of thin film [7], [8], [9] type in which the substrate is etched away on the back side. The natural frequency of the material and the thickness are used as design parameters to obtain the desired operating frequency. BAW devices have natural temperature compensation, often dependant on the material used for the uppermost reflector layer [10]. There are many fabrication challenges and issues are to be taken care by optimization of the process. Performance of designed BAW resonator for wireless applications is better studied and analyzed by optimizing the control parameters. This paper proposes the application of simpler and straight forward method by using Taguchi's orthogonal arrays.

1.1 Orthogonal Array

Taguchi's method with Orthogonal array matrix is comparatively structured and is been widely used from 1940's for designing the experiments. Performing few experiments can aid for convergence towards optimal values for efficient design. Widespread applications of Orthogonal array implementation ranges from Electromagnetics **[11],** cutting parameters for surface roughness measurement **[12],** Polymerase Chain reaction (PCR**)** **[13].** In general, fabrication of thin films involves higher costs and is also time consuming. Taguchi's method reduces the cost and time factor by applying orthogonal matrix combinations.

2. Experimental and simulation details

In this study the novel iterative implementation of Taguchi's method of orthogonal array was used for optimizing the efficient design values of thin film BAW resonator. Structure of BAW resonator, as shown in figure 1, includes the top aluminum layer followed by the piezo layer then the aluminum layer and finally the silicon layer. The variates considered in this experimentation includes thickness of Surficial Aluminum layer – A ranging from 0.1µm to 0.2 µm, Thickness of piezo layer –B ranging from 8 µm to 11 µm , Voltage applied to piezo ranging from 0.75 to 1.25 V and the width of resonator ranging from 800 µm to 1200 µm. In order to select the parameters appropriately array based matrix was implemented. The variables considered for simulation stretches with element spacing for all the parameters relative to their parametric values.L4 and L9 arrays **[14]**in orthogonal matrix was considered for study with possible multivariate terms.

Experimentation was performed by applying the parametric combinations following orthogonal array matrix to optimize the displacement. We used COMSOL Version 5.0 , MEMS MODULE to compute the Eigen modes and to apply the same for the frequency analysis. The simulated result presents the Q-factor and admittance range for the frequency designed. This study helps for the better optimization of the parameters involved in designing of BAW resonator for wireless applications.

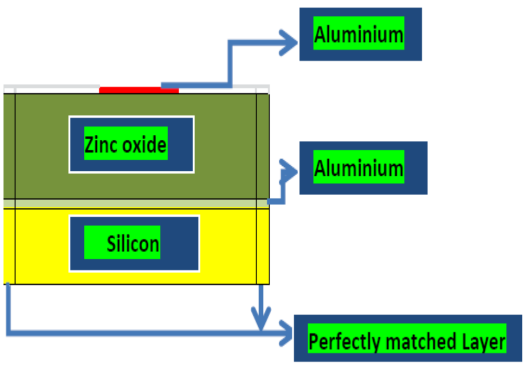

Figure 1. Basic structure of BAW resonator

3. Results and Discussion

As discussed we have used L4 and L9 Taguchi's orthogonal arrays for our simulations. For L4 array thickness of A was varied from 0.175µm to 0.2 µm, thickness of B was varied from 8.5 µm to 9.5 µm and width of entire resonator was varied from 900 µm to 1000 µm. The result obtained is as summerised in table 1. It can be seen that the displacement was highest when the thickness B is less. The result was not conclusive and for the more rigorous simulations we had taken L9 array where the voltage applied to resonator was chosen as the fourth parameter in simulation study.

Thickness of A (µm)	Thickness of B (µm)	Width of entire resonator (µm)	Displacement (µm)
0.175	8.5	900	$9.23x10^{-4}$
0.175	9.5	1000	4.85x10-5
0.2	**8.5**	**1000**	**1.47x10-3**
0.2	9.5	900	5.24x10-5

Table 1 L4 array based results

For the L9 array four parameters were varied for simulation study and are as given. Thickness A varied from 0.175 µm to 0.225 µm, thickness B varied from 8.5 µm to 10.5 µm, width of resonator varied from 900 µm to 1100 µm and the applied voltage varied from 0.75V to 1.25 V. The results obtained are summerised in table 2. The variation in the displacement of resonator was observed in range from minimum of $1.75x10^{-5}$ µm (figure 2) to $1.83x10^{-3}$ µm (figure 3). The row shown in red is for the maximum displacement while the green row shows the combinations for minimum displacement.

Thickness of A (µm)	Thickness of B (µm)	Voltage applied (V)	Width of resonator (µm)	Displacement (µm)
0.175	8.5	0.75	900	$3.6x10^{-4}$
0.175	9.5	1	1000	$5.06x10^{-5}$
0.175	10.5	1.25	1100	$2.77x10^{-5}$
0.2	8.5	1	1100	$1.47x10^{-3}$
0.2	9.5	1.25	900	$6.55x10^{-5}$
0.2	10.5	0.75	1000	$1.75x10^{-5}$
0.225	8.5	1.25	1000	$1.83x10^{-3}$
0.225	9.5	0.75	1100	$4.36x10^{-5}$
0.225	10.5	1V	900	$2.45x10^{-5}$

Table 2 L9 array based results

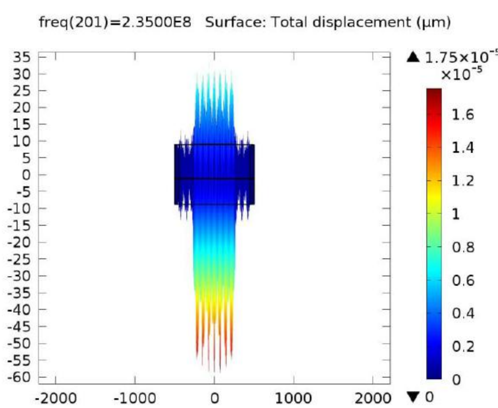

Figure 2. Simulation result for the minimum displacement

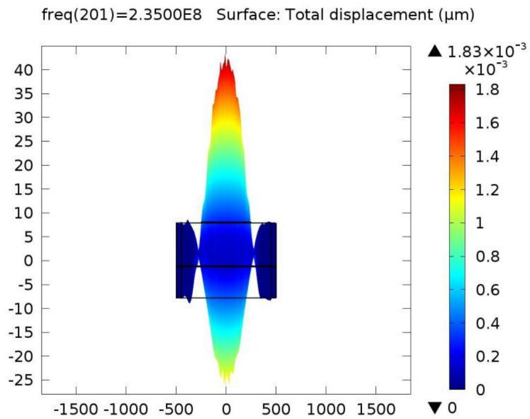

Figure 3. Simulation result for the maximum displacement

The analysis of the results is very clear from the bar graph shown in figure 4 where the scales are adjusted for the easy understanding. The detailed study of the simulation results reveals that the displacement can be varied as per the applications. The maximum displacement was observed when the thickness B is minimum and the applied voltage is maximum. Major effective parameter for the displacement variation was observed to be the thickness B. Maximum value of thickness B gives the minimum displacement even for the high value of voltage. Thickness A is less effective but the higher value of this suggestive for the large displacement of BAW resonator. It can be clearly seen that for the experiment 7 the displacement is maximum and experiment 6 results in the minimum displacement.

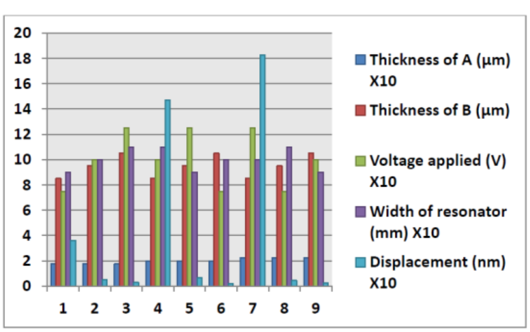

Figure 4. Comparison of the BAW resonator displacement based on the various parameter variations

Experiments were also helpful to find the variation in admittance and quality factor with respect to the resonant frequency. Rising trend for admittance (figure 5) and quality factor (figure 6) are indicative for the optimized parameters of experiment 7 which also gives the maximum displacement.

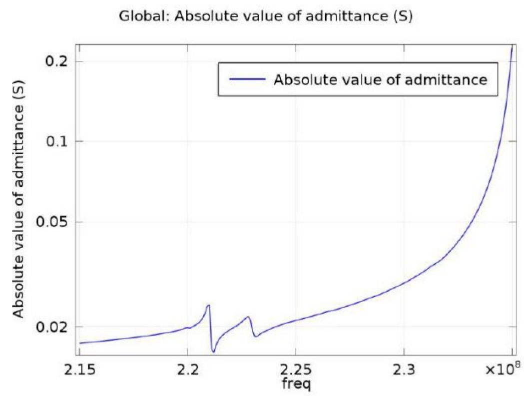

Figure 5. Absolute value of admittance for the experiment number 7 optimized for the maximum displacement

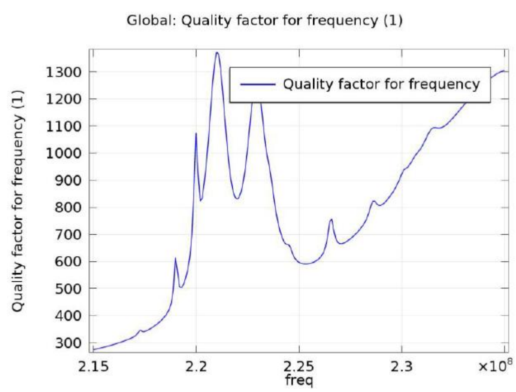

Figure 6. Variation in quality factor for the experiment number 7 optimized for the maximum displacement

Deteriorating trend for admittance (figure 7) and quality factor (figure 8) are indicative for the optimized parameters of experiment 6 which also gives the minimum displacement. Thus the simulation study gives the confidence to the designer to save the design time for the cost effective design.

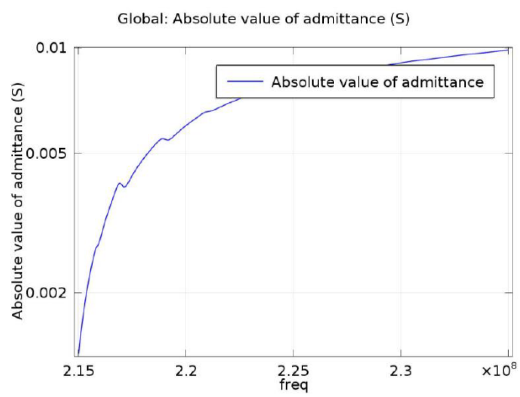

Figure 7. Absolute value of admittance for the experiment number 6 optimized for the minimum displacement

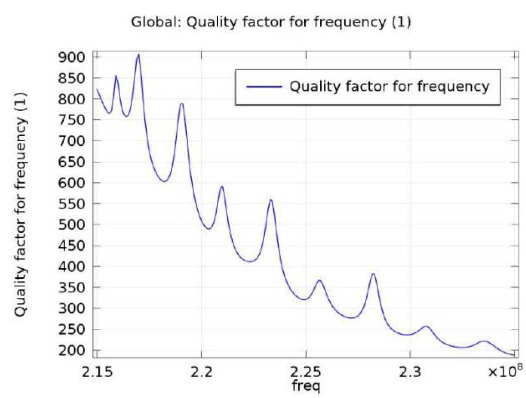

Figure 8. Variation in quality factor for the experiment number 6 optimized for the minimum displacement

4. Conclusions

With Comsol simulation above analysis provides vital information for the designer to optimize parameters in designing complex BAW resonator structures. Analysis aids to extend the futuristic operating frequency to higher ranges for wireless communication applications. This work improves electronic device design by reducing the fabrication efforts and will be very useful to minimize the design errors.

5. Acknowledgement

This project received funding from the Research fund of "Research & Development Program", Manipal University Dubai. The authors wish to thank and acknowledge the support of the research management team at Manipal University, Dubai for the active support rendered to persuade with this research project.

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