Different Parametric Analysis of One Port SAW Resonator using COMSOL

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Abstract

In this paper, a one-port SAW resonator with various operating frequencies is simulated using COMSOL Multiphysics. The resonator can be achieved in two ways one is a single IDT having a finite electrode over a piezoelectric substrate another is a short IDT with reflecting grating at the end of the IDT. SAW devices can be used as sensor and actuator delay line, signal processing unit, filter and resonators. Surface Acoustic Wave is one of the key components in an electronic circuit. A SAW is a mechanical wave, and this wave is excited on the piezoelectric substrate when a voltage is applied to the electrode. Distance between the two electrodes in the IDT decides the frequency of the propagating wave.

Keywords: - *SAW, Resonators, IDT, COMSOL Multiphysics.*

INTRODUCTION

Lord Rayleigh first introduced the surface acoustic in 1885; he described surface acoustic wave propagate in piezoelectric materials[1]. The Rayleigh wave propagates along the surface of the anisotropic materials, half-space the amplitude decaying exponentially away from the surface of the substrate [2]. White et al. explained an easy way to generate a surface acoustic wave by using an interdigital transducer. Hence the SAW devices have played an important role in many fields. SAW devices consist of a metal Interdigital transducer(IDT) on the surface of the piezoelectric substrate [3]. When an alternating voltage is applied on the IDT, then strain is produced on the piezoelectric substrate, and due to strain, an elastic wave travels along the surface of the substrate. SAW devices are two types one is Rayleigh wave and Love waves[4]. The propagation of SAW waves depends on the properties of the materials substrate, the dimension of the electrode, and the crystal cut. SAW devices can be used transversal filter, unidirectional IDT filters, resonator filters [5]. In the below figure, finger P represents pitch, a represent width, and w represents the overlapping area of the electrode. The pitch of the SAW devices is equal to half of the wavelength [6]. Relation between Eigen frequency and pitch of the SAW devices can be found using the formula

$$f = \frac{v}{2p} \qquad (1)$$

where f is the eigenfrequency, v is the velocity of the SAW devices, and p is the pitch of the IDT. Lithium niobate, lithium tantalate, and quartz are piezoelectric materials that have been used in the SAW device. In this work, we vary the metallization ratio, then the width of the IDT increases and the corresponding eigenfrequency and velocity decreases.

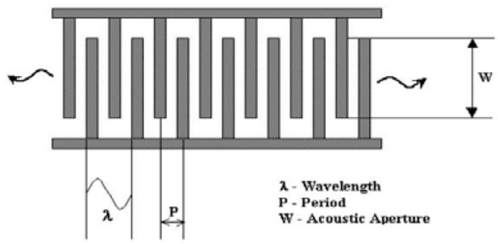

Figure 1: Interdigital Transducer (IDT)[7]

CONSTRUCTION OF THE RESONATOR

A. Geometry

Table 1: Parameters to Construct the Device

Sl. No.	IDT width [um]	Finger Pitch [um]	Electrode thickness [um]	Substrate thickness [um]	Substrate Width [um]
1	1.1	2.2	0.1	10	4.4

With the help of the Geometry sub-node under the component node, we have drawn the two rectangles; one is an electrode above another rectangle (piezoelectric substrate). An electrode is made of aluminium materials, and its property has been taken from the COMSOL library, and the property piezoelectric substrate has been taken from [8]. The one port structure is shown in Figure 2. The dimension of the one-port resonator has been shown in Table 1.

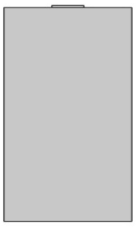

Figure 1: IDT with Piezoelectric Substrate

SIMULATION METHODOLOGY

A finite Number of IDT fingers is placed on 128o rotated Y-cut X propagated lithium niobate is used as a piezoelectric substrate [9]. A single electrode is used for appropriate boundary conditions. In this paper, we have used a 2D structure for the simulation piezoelectric substrate property, as shown in Table 2 and Table 3, respectively. In the 2D model bottom boundary surface of the structure is fixed, and all other boundary surfaces are stress-free [5]. Periodic condition is applied both left and right boundary of the model, and the expression for the periodic boundary condition has been shown in the given below. After completing the geometrical structure, we used the triangular mesh, and the element size is extra fine. The meshing figure is shown in Figure 3.

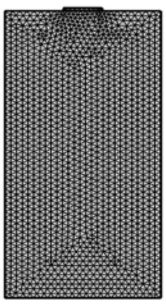

Figure 3: Meshing of the Resonator structure

After meshing, we got the number of boundary elements is 160, the number of elements is 2857, and the minimum element quality is 0.6218. Aluminium material is used for electrode, and its property has been taken from the material library of the COMSOL [10]. One voltage is applied to the electrode of the IDT fingers where the notation indicates that the surface is normal to the crystal Y-axis and the wave propagates in the crystal Z-direction. Another case is 128^o Y–X lithium niobate. This is a rotated Y-cut. The surface normal makes an angle 128^o with the crystal Y-axis, and the wave propagates in the crystal X-direction. The density of the substrate is $4700 Kg/m^2$. The periodic expression condition is given below.

$$u(x + mp) = u(x)\exp(-j2\pi\gamma m) \quad (2)$$

$$V(x + mp) = V(x)\exp(-j2\pi\gamma m) \quad (3)$$

$$\Gamma_R(u, V) = \rho\, \Gamma_L(u, V) \quad (4)$$

Where γ is called propagation constant, u is called displacement; Vis called piezoelectric potential, and m identifies the integer numbers.

Table 2: piezo-elastic constant

0	0	0	0	4.46	0.4
-1.77	4.46	-1.59	9.12	0	0
1.68	-2.67	2.4	0.59	0	0

Table 3: Coupling co-efficient

20.3*e10	7.23*e10	6.02*e10	1.07*e10	0	0
7.23*e10	19.4*e10	9.06*e10	0.89*e10	0	0
6.02*e10	9.06*e10	22.03*e10	0.81*e10	0	0
1.07*e10	0.89*e10	0.81*e10	7.49*e10	0	0
0	0	0	0	5.63*e10	- 0.44*e10
0	0	0	0	- 0.44*e10	7.9*e10

Table 4: Relative Permittivity

44	0	0
0	37.9	-7.81
0	-7.81	34

RESULTS AND DISCUSSIONS

Figure 4 show the simulated total displacement of one port resonator for one electrode structure in the frequency domain. We plotted the graph between total displacement VS frequency at point 3 of the one-port resonator and also plotted admittance Vs frequency which is shown below.

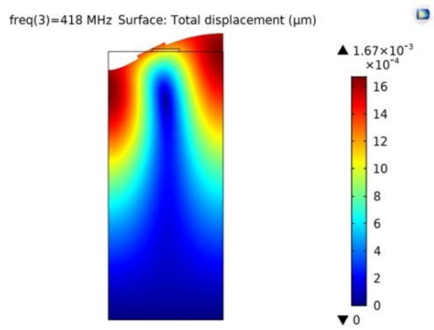

Figure 4: Surface displacement profile of the Resonator at Resonance frequency in X Direction

We also studied taking different metallization ratios and corresponding eigenfrequency, which is shown in Table 4. From the plot between Eigen frequency vs metallization factor, we conclude that eigenfrequency is exponentially decreasing with increasing the metallization ratio and also, we studied the velocity vs metallization ratio, the velocity exponentially decreases with increasing the metallization ratio. It means that velocity and eigenfrequency are inversely proportional to the metallization ratio due to the load effect.

Metallization ratio means the ratio of width ‘a’ of the electrode to the pitch ‘P’ of the IDT if we will take the less metallization ratio.

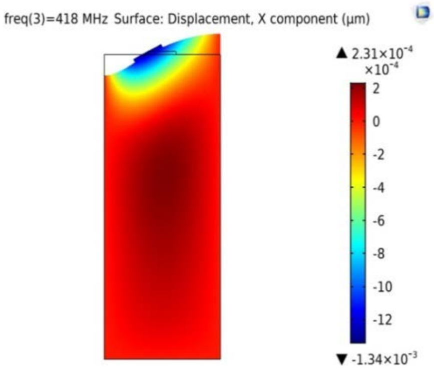

Figure 5: Surface displacement profile of the Resonator at Anti resonance frequency in X Direction

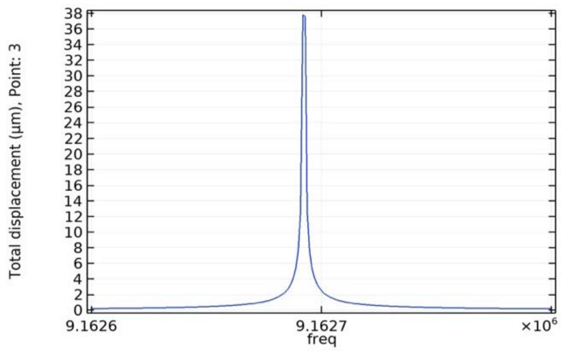

Figure 6: Total Displacement of a point on the Resonator structure

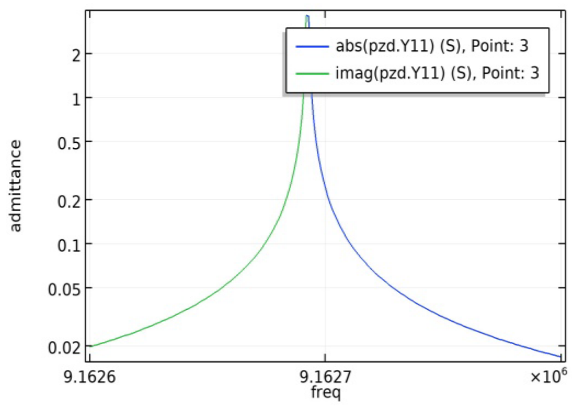

Figure 7: Admittance plot of the Resonator

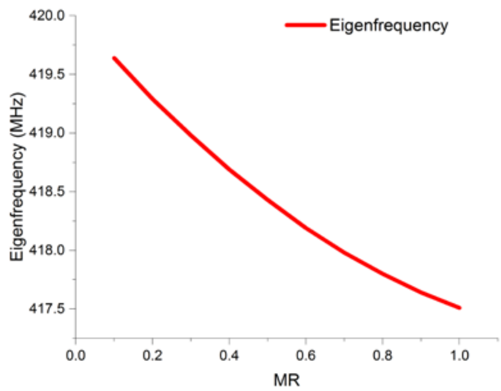

Figure 8: Variation of Resonance frequency of the device with respect to Metallization Ratio

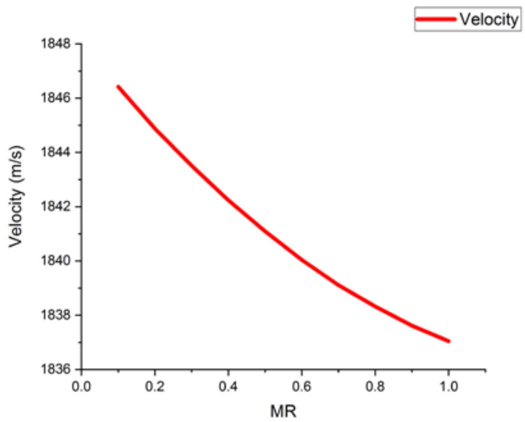

Figure 9: Variation of Velocity of the SAW with respect to Metallization Ratio

Table 5: Metallization Ratio with Eigen Frequency and Velocity of the SAW

Sl. No.	Metallization Ratio	Resonance frequency (MHz)	Velocity (m/s)
1	0.1	419.64	1846.416
2	0.2	419.29	1844.876
3	0.3	418.98	1843.512
4	0.4	418.69	1842.236
5	0.5	418.43	1841.092
6	0.6	418.19	1840.036
7	0.7	417.98	1839.112
8	0.8	417.80	1838.32
9	0.9	417.64	1837.616
10	1.0	417.51	1837.044

A. Admittance VS Frequency

The result of the simulation of the conventional SAW resonator is shown in Figure 4. And the total displacement and X-displacement of the resonator at the resonance frequency is 418MHz, and substrate depth is 4.4µm. In figure 1 that the displacement is approaching zero after the 2λ depth of the substrate. Which shows the nature of Rayleigh wave SAW. The resonance frequency of the resonator is the frequency at which susceptance is zero. Normalized frequency is expressed in the following expression f0 = 2*pf/v0.‘v0’ is called the free surface velocity of the substrate. The total displacement vs frequency plot has shown in the above Figure 3. At frequency, 9.1627MHz substrate gives the maximum displacement that is 37μm. The admittance curve is shown in Figure 7.

CONCLUSION

The simulation one electrode of the IDT on the piezo-substrate in SAW resonator using FEM in COMSOL. We used the eigenfrequency study provided by COMSOL. It is used to calculate the Phase velocity and resonance frequency of the SAW resonators. We have used a massless electrode over the piezo-substrate to avoid the mass loading effects. Eigen frequency and velocity of the one-port SAW resonator is exponentially decreasing with increasing metalization ratio.

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