Surface Acoustic Waves Based MEMS Resonator

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Abstract – In recent years, there has been an exponential growth in wireless communication systems. This has been possible due to the manufacture of small size high performance devices. SAW resonators are key component for Morden communication systems they are used as narrow band filter, oscillator, RFID tags, sensors etc. They are greatly contributing to the growth. SAW technology is low cost, rugged, lightweight and extremely low power consuming. The operation of SAW devices is based on the propagation of waves on the piezoelectric substrate. SAW resonators employing reflection grating are employed for precision filtering and oscillators. In this paper the simulation of SAW resonator is shown $LiNbO_3$ as piezoelectric substrate. COMSOL Multiphysics is used for simulation.

Keywords – SAW Resonator, IDT, COMSOL, MEMS, LiNbO

I. INTRODUCTION

Surface Acoustic Wave (SAW) is a mechanical wave that propagates along the surface of the piezoelectric substrate. It is also known as Rayleigh Wave, composed of coupled transverse wave and longitudinal wave. The velocity of the acoustic wave is almost five times lower than the electromagnetic wave thus resulting in construction of small size devices.

A basic SAW device consist of input and output IDT fabricated on a piezoelectric substrate by means of photolithography technique. [1] Due to piezoelectric coupling the applied electric voltage causes mechanical deformations or acoustic waves.

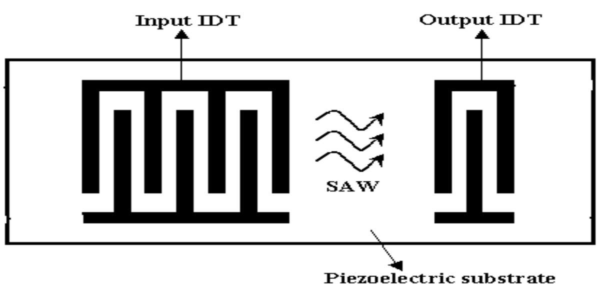

Figure 1. Basic SAW device

Commonly used piezoelectric substrates are Lithium Niobate ($LiNbO_3$), Lithum tantalite ($LiTaO_3$), and quartz. [1] $LiNbO_3$ is mostly used as the piezoelectric substrate as it an excellent acousto-optic material for SAW device and has high electromechanical coupling coefficient.

This paper highlights the principle of operation, design parameter and equivalent circuit model for two- port SAW resonator.

II. PRINCIPLE OF OPERATION

The operation of the SAW device is based on acoustic wave propagation on the surface of the piezoelectric substrate. Thus the wave can be trapped or modified while propagating on the surface.

The surface wave is excited electrically by means of the IDTs. The input IDT launches and output IDT receives the wave [1]. The frequency of the generated wave can be changed by controlling the pitch of the IDT. The input or output IDT may be same or different depending on the function which the device has to perform.

IDT is a comb shaped structure consisting of interleaved metal electrodes whose function is to transform electrical energy into mechanical energy and vice – versa by means of piezoelectric effect. In basic or simple structure the space between electrode finger and overlap width of any two adjacent fingers are both constant [3]

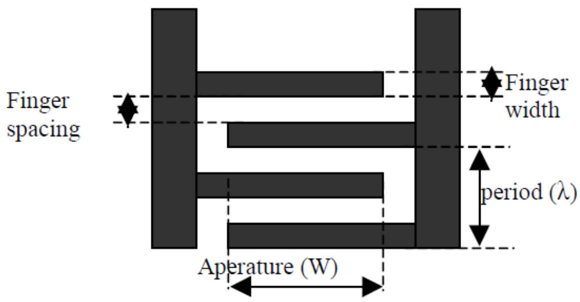

Figure 2. IDT

III. RESONATOR DESIGN

A. SAW Resonator Structure

SAW resonator consist of transmitting and receiving IDT, piezoelectric layer and reflectors on each side.

SAW devices use piezoelectric substrate for propagation of wave. SAW is launched when an electrical signal is applied to the input IDT on the surface of the piezoelectric substrate. Electrical signals are transformed into mechanical waves at the input IDT. These waves are launched and converted back to the electrical signal at the output IDT, the reflector are used to minimize the acoustic losses.

Piezoelectric equations governing the conversion from electrical to mechanical and vice versa are:

Electrical Displacement-

$$D = [e]\,[S] + [\varepsilon]\,E \qquad (1)$$

Where,

S = strain
E = electric field intensity

Mechanical Stress –

$$[T] = [c]\,[S] - [e^t]\,E \qquad (2)$$

Where,
$[e^t]$ is a 6*3 matrix.

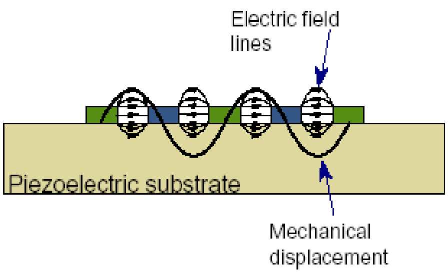

Figure 3. Piezoelectric effect

B. Resonator Theoretical Design

SAW resonator is designed using array of electrodes known as IDT. The input IDT generates spatially non- uniform time varying electric field when stimulus with a sinusoidal electrical signal. These fields generate stress at the surface of the piezoelectric substrate resulting in the generation of the acoustic wave. Another important component of the SAW resonator is the reflector consists of a set of metal strips, shorted or open – circuited and acts within their stop band as mirror reflecting the incident waves thus forming resonant cavity and reducing acoustic losses.

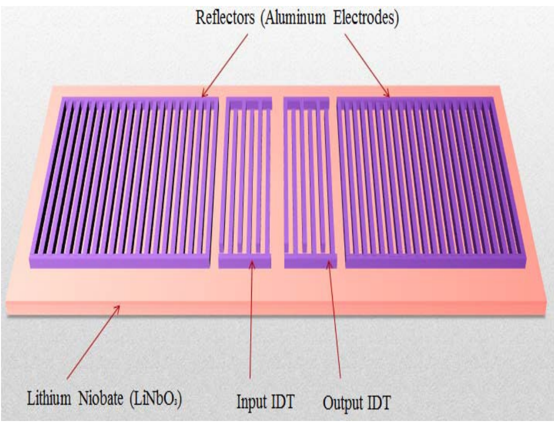

Figure 4. SAW resonator

The equivalent circuit model provides the necessary initial which allow designer to determine the major parameter of interest. The equivalent circuit of the SAW resonator is given below. The components describe the propagation of the acoustic wave within the cavity. Near the resonance frequency, the device act as a resonator which can be described using circuit elements namely C_x, R_x, L_x and C_f[2]

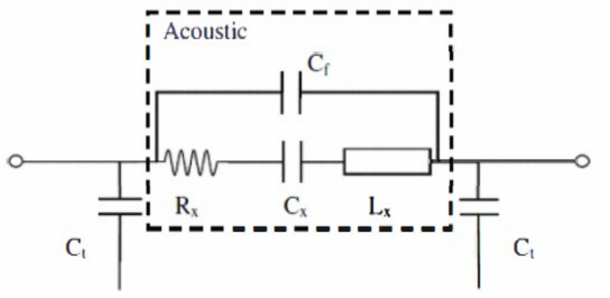

Figure 5. Equivalent circuit model for SAW resonator

C. Parameter of Resonator

The important design parameters are shown in the figure given below.

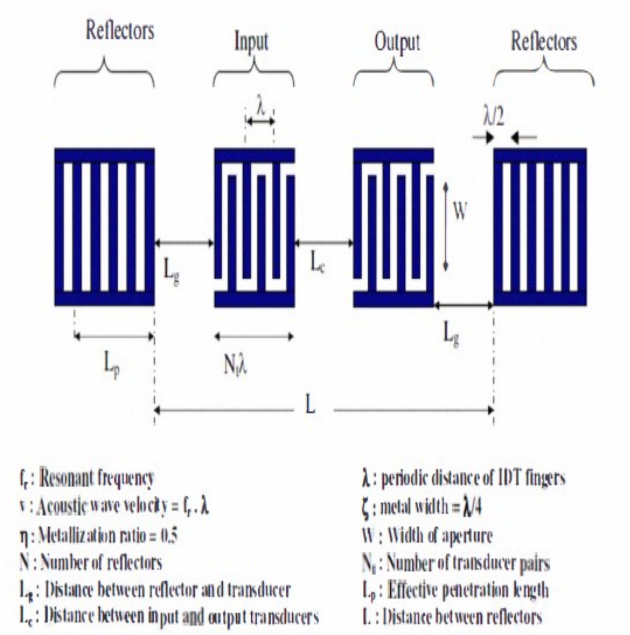

Figure 6. Key design parameter for resonator

The reflectors array of shorted electrodes. Shorted electrodes have been proven to have less spurious effects compared to the open electrodes [2]. Hence, they are used. The period of the reflector is half of the wavelength (λ/2).

The relationship between resonance frequency and wave velocity is given by:

$$F = \frac{V}{\lambda} \qquad (3)$$

Where,
F is the resonant frequency

v is the acoustic wave velocity
According to Datta [2] v for Lithium Niobate is 3488 m/s

λ is the periodic distance of IDT fingers.

The distance between the electrodes in the IDT is given by the relation:

$$\lambda = 2p \qquad (4)$$

Where,

p is the distance between the two electrodes of the IDT.

The design parameters are given in table below:

Design Parameter	*Values*
Resonance frequency	2.43 GHz
Periodic distance IDT finger, λ	1.43 µm
Acoustic wave velocity, v	3488 m/s

TABEL I. Design Parameters

D. Simulation using COMSOL Multiphysics

We have analysed the propagation of Rayleigh wave on YZ $LiNbO_3$ at 2.4 GHz. The geometry is drawn in 2D and piezoelectric physics is used. The piezoelectric substrate used is Lithium Niobate and Aluminium is used for IDT.

Since IDTs are periodic in nature consisting of positive and negative potential alternately, thus four electrodes are adequate to model two ports SAW resonator as whole. These electrodes function as two input and two output ports.

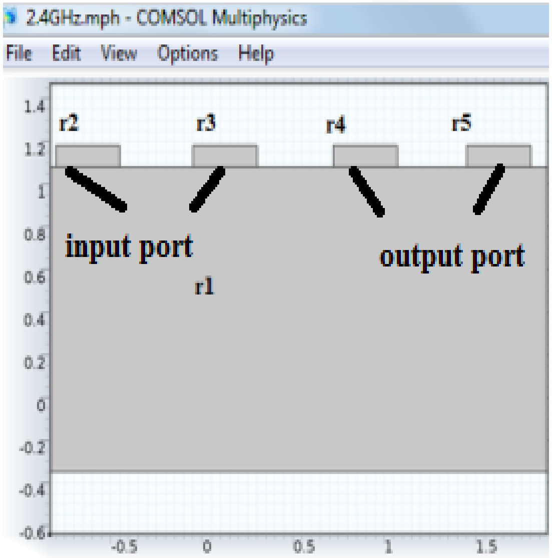

Figure 7. Geometry employed

Dimensions used are given below in the tabel

Al thickness	0.02 µm
Total length	2.68 µm
frequency	2.43 GHz

TABLE II. Dimensions used

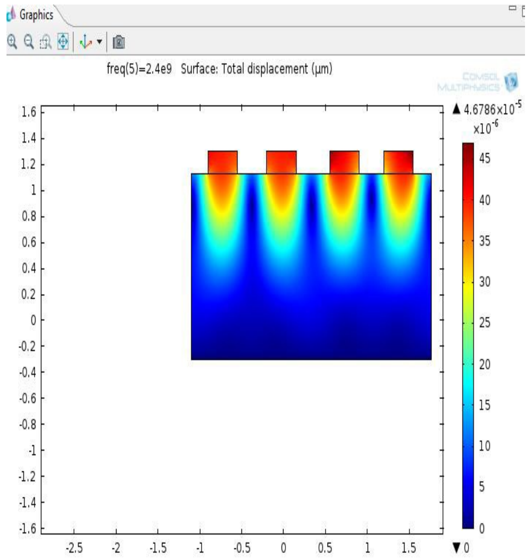

Figure 8. Frequency domain analysis

For frequency analysis 3V and 0V is set alternately to the input IDT. This shows that 3V sinusoidal is applied to the input IDT which produces strain in the piezoelectric substrate and generate acoustic wave that travel along the surface to undergo deformation.

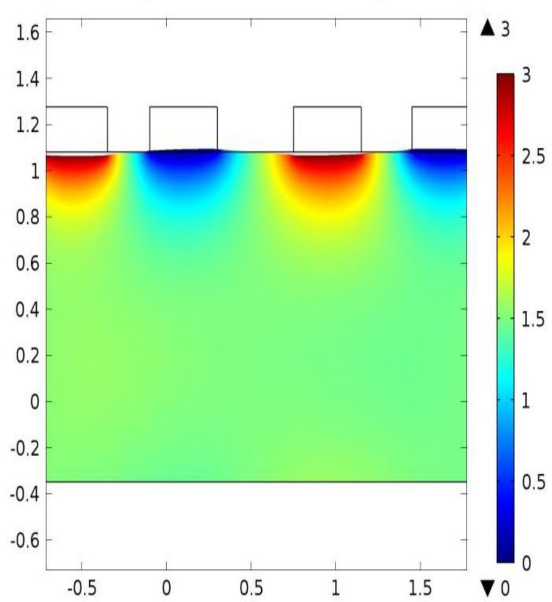

Figure 9. Potential plot

The displacement result at each point of time can be defined as a real part of equation:

$$U = U_a \cos(2\pi ft = U_p) \qquad (5)$$

The simulation results indicating the displacement of the $LiNbO_3$ is shown in the figure. This analysis was performed for the frequency ranging between 2.3 GHz to 2.5 GHz. When there is maximum displacement we have maximum resonance.

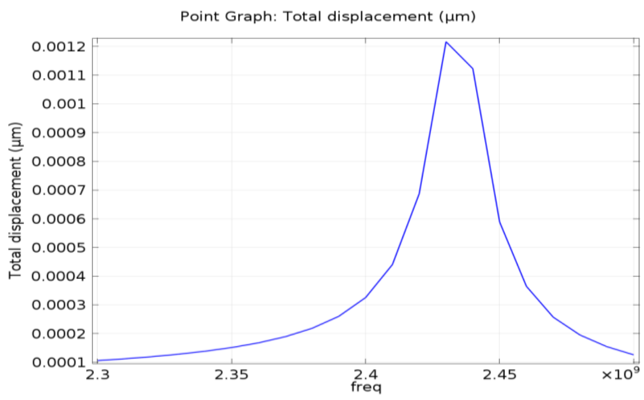

Figure 10. Resonance Plot

The Quality factor is the key parameter to evaluate the performance of the resonator. Quality factor is defined as the ratio of the stored energy to the energy lost per cycle. The Quality factor of the device is 278 which is quite good as SAW device have Quality factor up to 500 (theoretically).

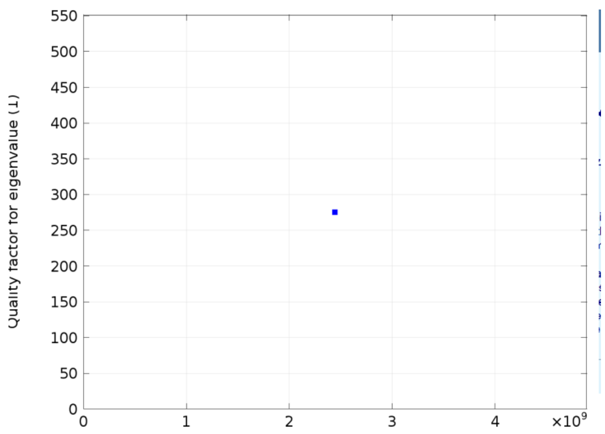

Figure 11. Quality Factor

According to the resonance frequency defination, the maximum energy is stored when the resonator vibrated at the frequency fn.

IV. CONCLUSION

Simulation of SAW resonator at 2.43 GHz on Lithium Niobate was presented in this paper. The critical design parameter were calculated based on theoretical equations with few assumptions were made. The Resonance graph shows the band pass response. The bandwidth is 8.8 MHz and the Quality factor is 278

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