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Design and Simulation of MEMS Based Surface Acoustic Wave Sensor using COMSOL Multiphysics

K. Prabakaran*, L. Sujatha
Dept. of ECE, Rajalakshmi Engineering College, Chennai, India
***Corresponding author: E-Mail: prabakaran083@gmail.com**

ABSTRACT

Micro Electro Mechanical System (MEMS) are small integrated devices that combines electrical and mechanical components in the range which sizes from sub micrometer level to millimeter level. The purpose of this study is to investigate the behavior of fingers various for surface acoustic wave interdigital transduction which could be subsequently used in biosensor application. Two groups of miniature SAW biosensor IDT fingers are successfully designed and will be fabricated using conventional lithography method. The combination of $LiNbO_3$ as a piezoelectric substrate and aluminium as an IDT show a good result in term of electrical characterization and frequency response. Since, SAW technology possess low cost, rugged, lightweight and extremely low power consuming. Their operation is based on the geometry of the device and the propagation of waves on the piezoelectric substrate. In this paper, the simulation of MEMS based SAW sensor is done with $LiNbO_3$ as the piezoelectric substrate using COMSOL Multiphysics. From the result, by increasing the spacing factor of IDT, SAW device has higher center frequency and thereby improves the sensitivity.

KEY WORDS: SAW, MEMS, IDT and COMSOL Software.

1. INTRODUCTION

MEMS can sense, control and activate mechanical processes on microscale and function individually or in arrays to generate effects on the macro scale. The micro fabrication technology enables fabrication of large arrays of devices, which individually performs simple tasks, but in the combination can accomplish the complication functions. MEMS are not about any one application or device, nor they defined by a single fabrication process or limited to a few materials. There are some fabrication approaches that conveys the advantages of miniaturization, multiple components and microelectronics to the design and construction of integrated electromechanical structure with the neat structure.

Surface Acoustic Wave (SAW) device is commonly use wafers made from the quartz crystal $LiNbO_3$ or $LiTaO_3$ as piezoelectric materials. Even in the same material, propagation characteristics of the waves vary with the cutting angle or the propagation direction. Propagation characteristics of the wave include the propagation velocity, electromechanical coupling coefficient and temperature coefficient delay time. Propagation velocity affects the relationship between the pitches of the Inter Digitated Transducer (IDT) and the required frequency of the device. In addition, the electromechanical coupling coefficient is related to the device.

Background: The Surface Acoustic wave Biosensors for biomolecular interaction analysis (El Gowini and Moussa, 2010) which describes the new coupling concept that reduces the flow cell of the sample volume down up to 60nl. In this work, the Flow Injection Analysis (FIA) is gets integrated with the SAW detection unit for handling the samples automatically.

Theoretical analysis of wireless passive impedance-loaded SAW sensors (Wei Luo, 2009) proposed that impedance loaded sensor by means of analyzing the wireless support passive mode of SAW device. It compares the measurement between the simulation and practical environment and in result it shows the impulse response variation in time domain with respect to the resonance characteristics.

Lu (2016), proposed Humidity sensors based on photo lithographically patterned PVA films deposited on SAW resonators. This paper describes the fabrication of relative humidity sensor on gold electrodes SAW resonators which conveniences the integration and measurement of the clean contact parts in which it is reliable for different application requirements.

Shrinivas (1991), SAW flow sensor in the realization of SAW sensor in the form of faster response by propagating lamb waves in the thin membrane which get interface with the flow sensor. The derivation of both sensitiveness and the response time have been derived theoretically based on the heat variation of the device.

Surface Acoustic waves based MEMS resonator (Dixi and Jai, 2014) clearly describes the operation of the SAW device on the piezo electric substrate by the propagation of surface waves due to influence of electric field potential. In this paper, the employment of reflection grating is done for both oscillators and precision filtering.

2. MATERIALS AND DESIGN FACTORS

Principle: A kind of wave which exits in elastic body with a free surface, whose distribution is localized near the surface. Here, in case of earthquake, the wave travel along the surface of the ground after P-waves and S-waves travel through the earth. These waves defined as surface acoustic waves, it will travel only when the piezo electric material are used. The various type of used in SAW devices such as Rayleigh wave, leaky wave and long wave. According to their characteristics, they have been applied to the relevant application.

Design Factors: To design a SAW device or filter with a given resonant frequency fo and fractional bandwidth B (measured null to null on either side of the resonant frequency), we have to take into account the following specifications such as IDT (Inter Digitated Transducer)- Metals Choosing, Finger width, Spacing between the fingers, Aperture Length, Wavelength.

Acoustic Wavelength (λ): The width of each finger that results in this synchronous frequency is λ/4 and the interdigital spacing measured from Centre-to-Centre is λ/2. Where v0 is an acoustic velocity and f0 is central frequency.

$$\lambda = V0 / f0 \quad (1)$$

Number of Finger Pairs (N_P): Needed to achieve fractional bandwidth specification 'B' is

$$N_P = 2 / B \quad (2)$$

Impedance of IDT (Z): It should be matched with the impedance of the measurement system (typically Z= 50 ohm). The IDT behaves as a capacitive system determined by the number of finger pairs, their spacing, as well as the degree of overlap. Total Capacitance required is:

$$C_T = 1 / 2\pi f_0 Z \quad (3)$$

In Micro Electro Mechanical Systems, the devices are fabricated at the range of Micro level and the fabrications of such devices are costly. It is difficult to fabricate every design and check the performance of those devices, so we simulate the devices using the COMSOL software. The material dimensions are shown in Table.1.

Table.1. Proposed Saw Structure Dimensions

IDT Parameters	Dimensions	IDT Parameters	Dimensions
Size of finger width	300µm	Number of IDT finger	12
Size of finger length	4500µm	Aperture length	8
Size of finger spacing	Design 1- 300µm, Design 2- 450µm		

3. RESULTS AND DISCUSSION

In the Design 1, the metal (Aluminium) is used in interdigitated transducer and the sensing layer is made up of Lithium Niobate between the two IDT's. The piezoelectric material used as the substrate. Here the finger spacing is up to 300µm is shown in Figure.1.

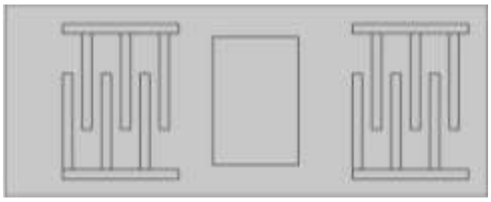

Figure.1. SAW Device

The input electrical signal is in the form of Eigen frequency applied as input to the both simple as well as proposed SAW device, for which corresponding displacement and potential will be obtained as output. The range of Eigen frequency is applied in the range of (1-5e5) and corresponding displacement and potential is noted for each input. Then, applied Eigen frequency versus Displacement and Electric Potential behavior is plotted for the proposed structure. Hereby, comparing both the study results of the stationary and Eigen frequency. Considering these design parameters of the SAW device, the following simulation and the measurement have been noted and shown in the Table.2 and shown in Figure.2 and Figure.4. The displacement graph and potential graph is shown in Figure.3 and Figure.5.

Table.2. Design 1 (IDT Spacing-300µm)

Eigen Frequency (e6)	Surface Displacement (µm)	Electric Potential-Low Range (v)	Electric Potential-High Range (v)
1	1.4	-3.31	3.51
2	2.2	-4.31	6.21
3	2.4	-1.80	4.52
4	3.0	-5.36	5.81
5	4.0	-5.86	6.96

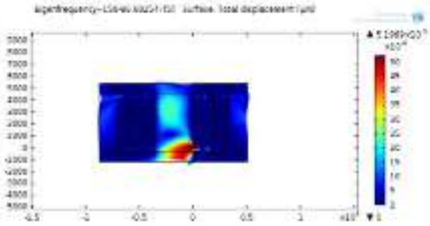

Figure.2. Displacement Flow- Design 1

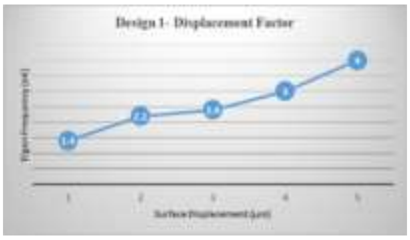

Figure.3. Displacement Graph- Design 1

In the Design 2, the finger spacing is up to 450µm. The metal (Aluminium) is used in interdigitated transducer and the sensing layer is made up of Lithium Niobate between the two IDT's. The piezoelectric material ($LiNbO_3$) used as the substrate, whose density is 4700kg/m^2, relative permittivity (84, 84, 30) and elasticity matrix (2.0289e+011[Pa]). By applying the value of the Eigen frequency, the corresponding displacement and potential are tends to be measured which is shown in Figure.6 and Figure.8. The displacement graph and potential graph is shown in Figure.7 and Figure.9.

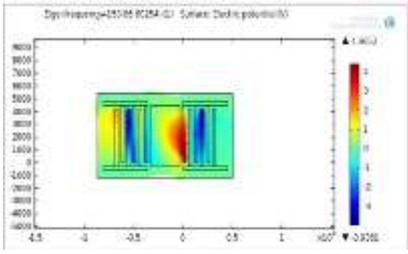

Figure.4. Potential Flow- Design 1

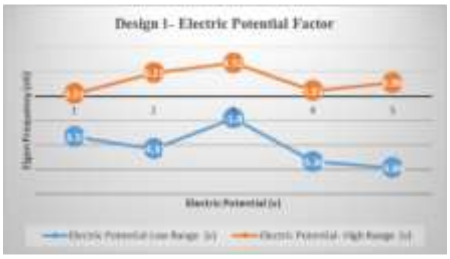

Figure.5. Potential Flow- Design 1

To summarize, the two dimensional SAW structure is designed by using quartz or glass substrate and the device is in contact with the piezoelectric material ($LiNbO_3$). The surface displacement and electric potential of the 2 devices have been calculated based on corresponding suitable given Eigen frequency. For the gas sensing application, the SAW device are designed with the 2 different IDT spacing factor for the three sets of range of frequencies. Thereby the capacitance of the SAW device using Lithium Niobate ($LiNbO_3$) is increased when compared to Zinc Oxide (ZnO). The comparative results of the null bandwidth of device is shown in the Table 5. This indicate strong leakage of acoustic energy on the substrate, thereby launching longitudinal waves. Thus the attenuation of sound waves leads to an acoustically driven phenomenon known as acoustic streaming. Further, the streaming velocities are computed with the help of time average and substrate thickness in contact with the piezoelectric domain.

The surface acoustic wave based MEMS gas sensor was designed and the operating frequency of the saw device was found to be 0.006 GHz and 0.004GHz. The maximum sensitivity is obtained, since the gas sensor is operating in GHz range. The maximum shift in the resonant frequency is nothing but the maximum partial density of absorbed gas. As the partial density of absorbed gas increases the resonant frequency shift also increases. Saw gas sensor has the advantages of small size, low cost of fabrication, long life time, high sensitivity and selectivity. Saw gas sensor are mainly used for chemical industries, military applications and also used in wireless sensing applications.

Table.3. Design 2 (IDT Spacing- 450µm)

Eigen Frequency (e6)	Surface Displacement (µm)	Electric Potential -Low Range (v)	Electric Potential - High Range (v)
5.02731	1.2031	-7.0877	8.4384
6.49870	2.1643	-9.3182	10.049
7.14483	5.9065	-6.7704	6.8425
8.11479	8.6841	-6.7852	16.504
9.126343	5.0408	-5.260	17.613

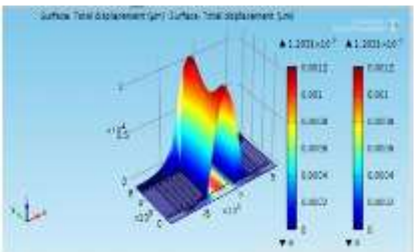

Figure.6. Displacement Flow- Design 2

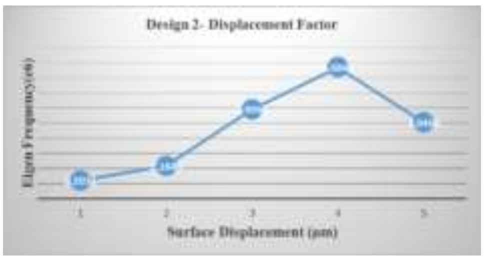

Figure.7. Displacement Graph- Design 2

From the theoretical, the number of IDTs is one of the parameters that affecting to the performance of SAW device. In this paper, the single IDTs were designed with the total of 12 fingers and hereby to increase the performance characteristics of the SAW Device by means of capacitance measurement are tends to be considered. It also shows that the number of finger is also affected to the device performance.

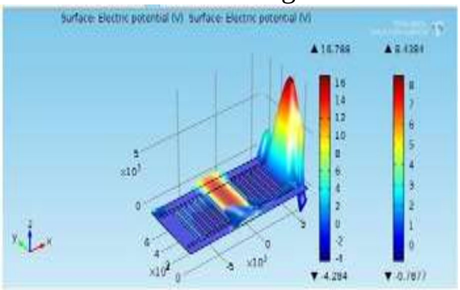

Figure.8. Potential Flow- Design 2

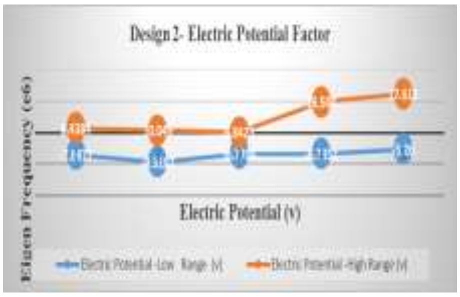

Figure.9. Potential Graph- Design 2

Table.4. Central Frequency and Capacitance Measurement

Design Method	Zinc Oxide (ZnO) V_s – 3954 m/s		Lithium Niobate ($LiNbO_3$) V_s – 3880 m/s	
	MHz	nF	MHz	nF
DESIGN 1 (300µm)	$F_0 = 6.6$	C = 0.47	$F_0 = 6.5$	C=0.49
DESIGN 2 (450µm)	$F_0 = 4.4$	C = 0.72	$F_0 = 4.2$	C=0.75

The study results of Design 1 and Design 2 are described in Table.2 and Table.3 respectively. The Central frequency and Capacitance measurement of the SAW device for 2 designs are calculated using the equations (1), (2), (3) shown in Table.4. The Null bandwidth of the device is shown in Table.5.

Table 5 Null Bandwidth (NBW)

No. of Fingers	Zinc Oxide (ZnO) V_s – 3954 m/s		Lithium Niobate ($LiNbO_3$) V_s – 3880 m/s	
	300 µm	450 µm	300 µm	450 µm
12 FINGERS	1.098E6	0.732E6	1.0776E6	0.7036E6
10 FINGERS	1.318E6	0.878E6	1.2933E6	0.8444E6
08 FINGERS	1.647E6	1.098E6	1.6615E6	1.0555E6

4. CONCLUSION

In this project, the SAW device with different number of IDT fingers and their structure are designed, fabricated and investigated for improving the sensitivity biosensor. The sensitivity of biosensor was studied through the center frequency, capacitance and null bandwidth value. Lowering the center frequency will improve the capacitance of the device. The center frequency can calculate from basic the result from capacitance measurement is proved.

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