ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Website: www.ijareeie.com

Vol. 6, Issue 2, February 2017

Study of Surface Acoustic Wave Sensor

K.Prabakaran[1], L.Sujatha[2]

PG Student [CS], Dept. of ECE, Rajalakshmi Engineering College, Thandalam, Tamilnadu, India[1]

Professor, Dept. of ECE, Rajalakshmi Engineering College, Thandalam, Tamilnadu, India[2]

ABSTRACT: Surface acoustic wave (SAW) sensors are a class of Micro Electro Mechanical System (MEMS), which rely on the modulation of the surface acoustic waves to sense a physical phenomenon. The sensor transduces the input electrical signal into the mechanical wave (vice-versa) and it tends to sense the change in the amplitude, phase, frequency and time delay between the input and the output electrical signal. They have many beneficial characteristics such as rugged compact structure, low cost, low attenuation, low power consumption and fast real time response and it also plays a vital role in the harsh environments, turbine generators, cryogenic sensing and multi-sensor spread spectrum system. This system proposes the design and analysis of MEMS based surface acoustic wave sensor for the biological and gas sensing applications by using the CAD tool and Comsol Multiphysics kit. Hereby, the IDT used in the sensor tends to be design in the three distinct dimensions to show the variation in the displacement and potential characteristics by varying the value of an input Eigen frequency given. In order to increase the sensitivity of the device, the IDT placed here in three different finger spacing such as 300µm, 450µm and 600µm. The parameters can be optimized by using the CAD tool for the better performance of the sensor and also the fabrication of SAW sensor is going to be done by using Intellifab.

KEYWORDS:SAW, MEMS, IDT and COMSOL Software

I.INTRODUCTION

In a solid material, an acoustic or elastic wave involves strains arising due to change in relative positions of atoms, and stresses arising out of internal forces tending to return the material to its equilibrium, unstrained state. Propagation of Acoustic waves involves stresses and strains. To ensure constructive interference and in-phase stress, the distance'd' between two neighbouring fingers (IDTs) is equal to half the elastic wavelength λR. The associated frequency is known as synchronous frequency. At this frequency, the transducer efficiency in converting electrical energy to acoustical is maximized. The output IDT works in a reciprocal manner, and converts mechanical SAW vibrations back into output alternating voltages. The surface outside the IDT regions need only be elastic, without being piezoelectric.

In Surface Acoustic Wave Devices, a surface acoustic wave travel on the surface of the piezoelectric materials is used. Piezoelectric materials are used for as electrical signals need to be transformed into the surface acoustic wave. Piezoelectric materials become deformed when an electrical field is applied. With this effect, waves can be generated by forming comb-shaped electrodes (described below as Inter Digital Transducers (IDT)), and applying signals to them. The acoustic wave velocity depends to some extent on the types of substrates or the kind of the waves utilized. The frequency of the generated waves can be changed by controlling the pitch of the IDT electrodes. Similarly, when SAW is arrive at the IDT, if the pitch of the IDT and SAWs match, an electrical signal is generated between the IDT electrodes.

The SAW Temperature Sensor on Quartz describes the design of the need for materials with useful SAW resonator properties and with the largest difference between temperature coefficients of frequency (TCF) for a resonator pair on a single substrate [1]. The Performance Prediction and Sensitivity Analysis of Saw Gas Sensors describes about input variables include the number of finger pairs, the electrode overlap, the separation distance of twin interdigital transducers on the substrate, the dimensions of the stable temperature-cut (ST-cut) quartz substrate, and the electrode thickness [2]. An Energy Autonomous 400 MHz Active Wireless SAW Temperature Sensor Powered by Vibration Energy Harvesting adopts direct temperature to frequency conversion using a lithium Niobate SAW resonator for both temperature sensing and high-Q resonator core in a cross-coupled RF oscillator [3]. Design and Analysis of SAW

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Website: www.ijareeie.com

Vol. 6, Issue 2, February 2017

Based MEMS Gas Sensor for the Detection of Volatile Organic Gases proposes the design and analysis of SAW based MEMS gas sensor for the detection of volatile organic gases [4]. Design and Fabrication of IDT SAW by Using Conventional Lithography Technique is to investigate the behaviour of fingers various for surfaceacoustic wave interdigital transduction [5]. Study of the Acoustoelectric Effect for SAW Sensors is to re-examine the theory and predictions of the acoustoelectric effect for SAW interactions with thin conducting or semi-conducting films [6]. A Bio-Inspired Pattern Recognition System for Tin-Oxide Gas Sensor Applications enables the emulation of a very large number of sensors typically found in biological systems [7].

II.DESIGN CONSIDERATION

To design a SAW device or filter with a given resonant frequency $f_o$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.
1. 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 v_0 is an acoustic velocity and f_0 is central frequency.

$$\lambda = V_0 / f_0 \quad (1)$$

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

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

3. Impedance of IDT (Z): Itshould 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:

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

4. Acoustic aperture (W): Overlapping region between those two fingers, in length units.

$$W = C_T / C_0 N_P \quad (4)$$

Where Co - capacitance per finger pair per unit length.
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 fabric at every design and check the performance of those devices, so we simulate the devices using the comsol software.

Comsol Software:
COMSOL Multiphysics is a finite element analysis, solver and simulation software/ FEA software package for various physics and engineering applications; especially coupled phenomenon. The package is a cross platform (Windows MAC, Linux). They are used for creating physics based applications.

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Website: www.ijareeie.com

Vol. 6, Issue 2, February 2017

TABLE 1 DIMENSIONS OF THE PROPOSED SAW STRUCTURE

S.No	IDT Parameters	Dimensions
1.	Size of finger width	300µm
2.	Size of finger length	4500µm
3.	Size of finger spacing	300µm, 450µm, 600µm
4.	Number of IDT finger	12
5.	Aperture length	8

The Model builder in COMSOL is the designing interface that is used to generate a physical design. The physical design may consists of many blocks that are connected together to form a device. The designed model is useless until certain parameters are set and boundary conditions are allotted. Model Builder has the facility to design both 2D and 3D models. It also supports user interactive graphics such as 3D projection using which a design made can be rotated and viewed along the three axes.

III. SIMULATION IN COMSOL

The surface acoustic wave device became a suitable shaped metallic thin film deposited on the surface of a piezoelectric crystal such as quartz or lithium niobate ($LiNbO_3$). Quartz is the most commonly used substrate because of its temperature stability for certain crystal orientations. The transducer consists of a sequence of metal electrodes, usually of aluminum, alternately connected to bus bars. Two IDTs are required in the basic surface acoustic wave device (SAW) configuration. A periodic electric field is produced when an *rf* source is connected to the input electrode, thus permitting piezoelectric coupling to a travelling surface wave. Direct coupling to a surface elastic wave is possible at the boundary of a piezoelectric solid if any of the components of strain at the surface is piezo electrically active**.** To ensure constructive interference and in-phase stress, the distance'd' between two neighboring fingers (IDTs) is equal to half the elastic wavelength λR. The associated frequency is known as synchronous frequency. At this frequency, the transducer efficiency in converting electrical energy to acoustical is maximized.

The output IDT works in a reciprocal manner, and converts mechanical SAW vibrations back into output alternating voltages. The surface outside the IDT regions need only be elastic, without being piezoelectric. The type of acoustic wave and the wave velocity generated in a piezoelectric material depends on the substrate material properties, the crystal cut, and the structure of the electrodes used to transform the electrical energy into mechanical energy is shown in "Fig. 1". The Rayleigh wave V-3 generated on the piezoelectric substrate has both a surface normal component and a surface parallel component with respect to the direction of propagation. The surface particles move in elliptical paths having a surface normal and a surface parallel component. The energy of the surface acoustic wave (SAW) is confined to a zone close to the surface and is of a few wavelengths thick.

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering
(An ISO 3297: 2007 Certified Organization)
Website: www.ijareeie.com
Vol. 6, Issue 2, February 2017

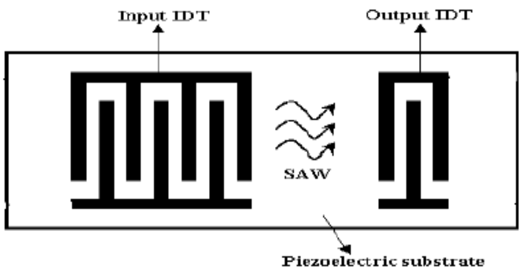

Fig. 1. SAW Device

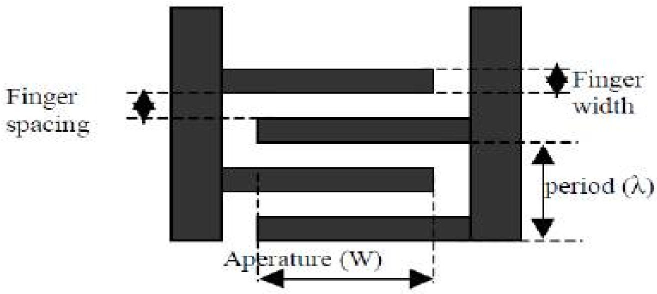

Fig. 2. IDT Structure

The IDT's are in form of two shapes either in comb model or in the conventional model. Mostly the conventional model is tends to be preferable which is shown in "Fig. 2".Two of the most important physical properties relating to surface wave propagation on a piezoelectric substrate are the wave velocity (*v*) and the electromechanical coupling coefficient *K2* of the piezoelectric substrate.

The2Dsolidstructureof the Proposed SAW deviceis designed using the model builder of Comsol.The "Fig. 4 and Fig. 5"shows Structure of the SAW device in 2D form and the corresponding Simulation of proposed Comsol structure. With the reference to above structural measurement of the predominant factors such as IDT (spacing, length and width), type of the substrate and the sensing layer. The design of this proposed SAW device will been in practice with the three distinct parameters according to their specific applications. The important classifiers that are tends to be noted while designing the SAW device such as elasticity matrix, coupling matrix relative permittivity and material density value. The entire value of the displacement and potential level of occurrences are tends to be varied according to the given Eigen frequency.

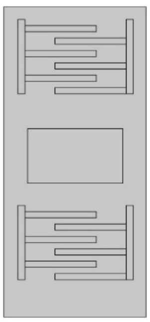

Fig. 3. 2D Structure of SAW

The purpose of this study "MEMS based SAW sensor" is to investigate the behavior of fingers various for surface acoustic wave inter digital transduction which could be subsequently used in biosensor application. SAW biosensor

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Website: www.ijareeie.com

Vol. 6, Issue 2, February 2017

using the IDT fingers are successfully designed and are going to be fabricated for the bio- sensing and gas- sensing applications.

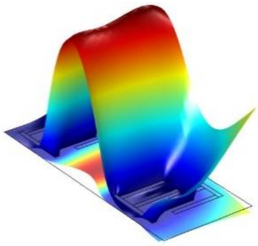

Fig. 4. Simulation – Proposed Structure

Here, the Zinc Oxide (or) Lithium Niobate acts as a piezoelectric substrate and aluminum acts as an IDT show a good result in term of electrical characterization and frequency response. Increasing number of IDT in SAW design (or) to decrease the spacing between the IDT fingers, has higher center frequency and thereby it can improve the sensitivity.

1. SAW Device - Design 1:In the Design 1 of SAW Device, 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 "Fig. 5".

The input electrical signal is in the form of Eigen frequency applied as input to the both simple aswell as proposed SAW device, for which corresponding displacement and potential willbe obtained asoutput. The range of Eigen frequency is applied in the range of (1-10e5)and corresponding displacement and potential is noted for each input. Then, applied Eigen frequency versus Displacement and Potentialis 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. Hereby varying the value of the Eigen frequency, the corresponding displacement and potential are tends to be measured which is shown in "Fig. 6" and "Fig. 7".

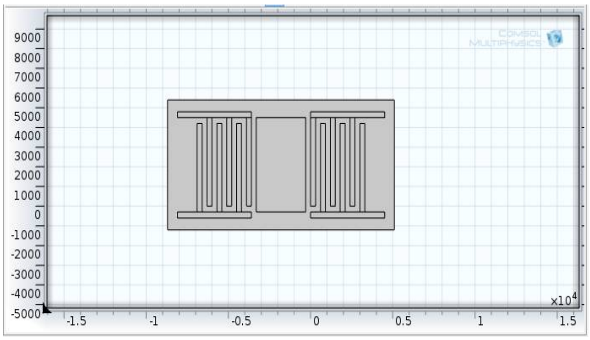

Fig. 5. Design of SAW Device

 DOI:10.15662/IJAREEIE.2017.0602034

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Website: www.ijareeie.com

Vol. 6, Issue 2, February 2017

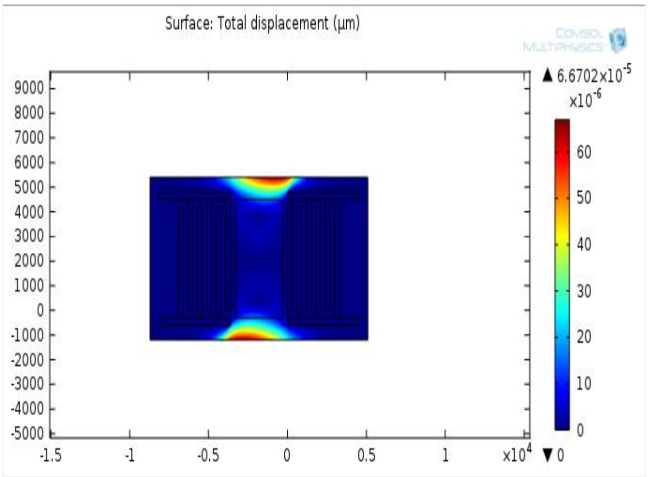

Fig. 6. Displacement Flow

2. SAW Device – Design 2: In the Design 1 of SAW Device, the metal (Aluminium) is used in inter digitated 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 450µm. By applying the value of the Eigen frequency, the corresponding displacement and potential are tends to be measured which is shown in "Fig. 8" and "Fig. 9".

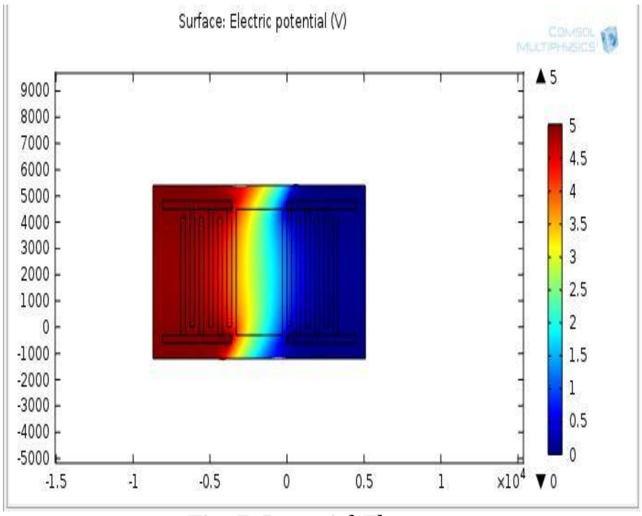

Fig. 7. Potential Flow

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Website: www.ijareeie.com

Vol. 6, Issue 2, February 2017

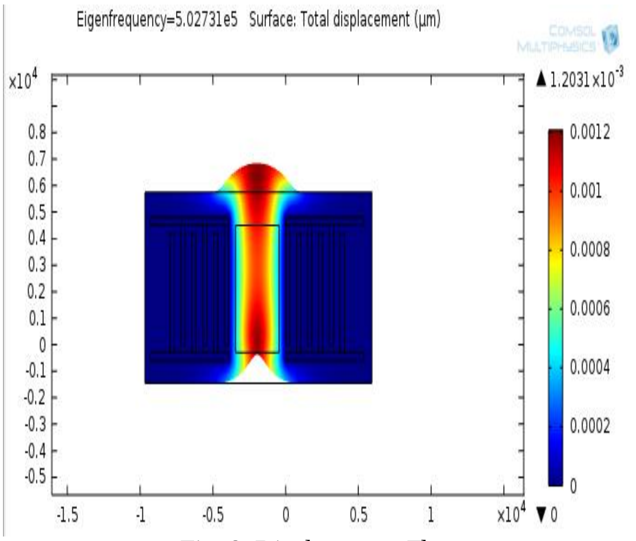

Fig. 8. Displacement Flow

3. SAW Device – Design 3: In the Design 1 of SAW Device, 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 600µm. By applying the value of the Eigen frequency, the corresponding displacement and potential are tends to be measured which is shown in "Fig. 10" and "Fig. 11".

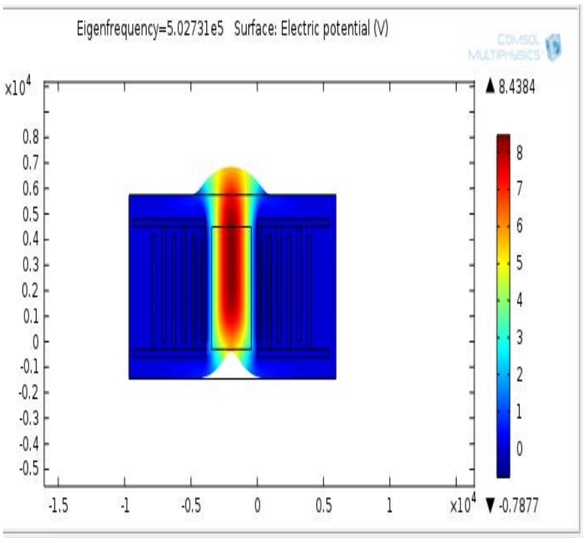

Fig. 9. Potential Flow

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Website: www.ijareeie.com

Vol. 6, Issue 2, February 2017

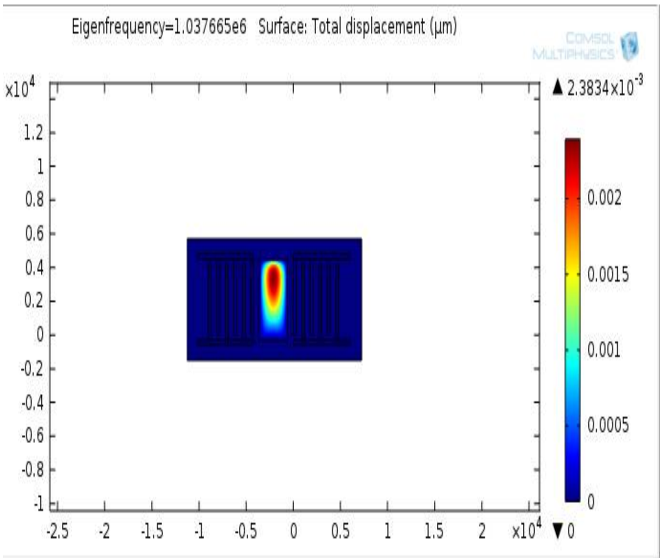

Fig. 10. Displacement Flow

Saw Fabrication Process: There are four important process steps that need to be followed in fabricating the SAW biosensor. The component consists of preparation of piezoelectric substrate, fabricate the sensing area and Interdigital transducer electrode preparation. All these components must be fabricated in several stages. For the first stage, the wafer starting with "Fig. 12": Conventional SAW Biosensor a) IDT with 10 cleaning by using standard cleaning procedure then fingers, b) IDT with 16 fingers. Continue with the oxidation process. Where, the oxide was grown on the wafer surface with the thickness around 1000 Å. The oxide is grown by using dry oxidation furnace for about 1 hour. The samples then deposited with Lithium Niobate ($LiNbO_3$) in order to form a layer of piezoelectric substrate. The sol-gel technique was used for growth $LiNbO_3$ layer on the sample surface. The third stage is to fabricate the sensing area on the sensor samples. The aluminium with thickness 500 Å was deposited onto sensor surface by using a thermal evaporator. Then the 1st mask is used for fabricating the sensing area pattern on the biosensor surface. The final stages are followed by fabricating the Interdigital transducer electrode finger. The sample then deposited with another aluminium layer with a thickness of 200 Å for IDT electrode.

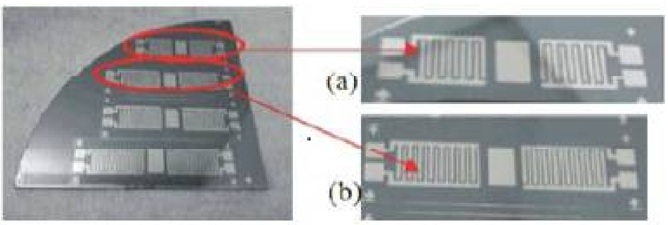

Fig. 12. Conventional SAW Biosensor a) IDT with 10 fingers, b) IDT with 16 fingers.

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Website: www.ijareeie.com

Vol. 6, Issue 2, February 2017

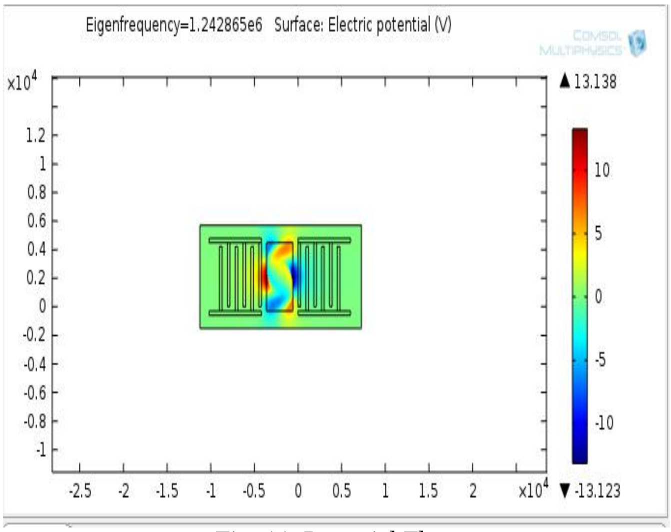

Fig. 11. Potential Flow

V. RESULT AND DISCUSSION

In this project, the IDT with different number IDT fingers structure are designed, fabricated and investigated for improving the sensitivity biosensor. The sensitivity of biosensor was studied through the centre frequency and capacitance value. The higher centre frequency will improve the sensitivity of biosensor device. The centre frequency can calculate from basic the result of IV, resistivity and CV then proved by using Bragg theories. 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.

TABLE 2 STUDY RESULTS – DESIGN 1

Eigen Frequency (e6)	Surface Displacement (µm)	Electric Potential (v)	Electric Potential (v)
1	1.440	-3.3162	3.5161
2	2.184	-4.3081	6.2105
3	2.415	-1.805	4.5281
4	2.93	-5.3668	5.8144
5	3.928	-5.8666	6.9652
6	1.712	-4.9117	3.2484
7	2.481	-4.5043	6.3775
8	1.789	-3.7607	4.8645
9	2.282	-4.6177	3.5167

To summarize, a three dimensional bi-directionally coupled fluid-structure interaction model, of a LiNbO3 based SAW device in contact with fluid loading, was developed to investigate the interaction of the device with the fluid domain and gain insights into the acoustic streaming phenomenon. Device surface displacement and fluid velocity profiles indicate strong coupling of the fluid with solid domain and leakage of acoustic energy into the fluid domain, thereby launching longitudinal waves into the fluid. This attenuation of sound waves leads to an acoustically driven phenomenon known as acoustic streaming. The model predicts fluid velocities in accordance with the experimentally reported values. Further, the streaming velocities computed as the time average of the first order fluid velocities indicate fluid recirculation beyond the initial fluid thickness in contact with the piezoelectric domain.

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Website: www.ijareeie.com

Vol. 6, Issue 2, February 2017

TABLE 3 STUDY RESULTS – DESIGN 2

Eigen Frequency (e6)	Surface Displacement (μm)	Electric Potential (v)	Electric Potential (v)
5.02731	1.2031	-7.0877	8.4384
6.49870	2.1643	-9.3182	10.049
6.90196	6.55	-6.5465	7.2824
7.14483	5.9065	-6.7704	6.8425
8.11479	8.6841	-6.7852	16.504
8.40507	4.0583	-7.021	8.4328
8.609617	7.3825	-4.284	16.788
8.760304	0.0117	-15.192	11.644
9.126343	5.0408	-5.260	17.613
9.338584	3.5252	-3.2982	16.971

The surface acoustic wave based MEMS gas sensor was designed and the operating frequency of the saw device was found to be 1.121 GHz. The maximum sensitivity is obtained, since the gas sensor is operating in GHz range. The maximum shift in the resonant frequency is for tetrachloroethene because of maximum partial density of absorbed tetrachloroethene. 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 4 STUDY RESULTS – DESIGN 3

Eigen Frequency (e6)	Surface Displacement (μm)	Electric Potential (v)	Electric Potential (v)
1.03766	2.3834	-1.2844	18.364
1.126488	2.1314	-2.7099	15.98
1.134709	6.341	-10.808	10.828
1.203625	2.461	-3.0119	16.311
1.248265	3.6937	-13.123	13.38
1.358061	6.7761	-25.573	25.852
1.443073	4.1302	-29.054	15.448
1.465073	4.70905	-12.989	12.992
1.474386	7.0806	-25.473	25.472
1.549169	4.4227	-31.81	15.821

The study results of Design 1, Design 2 and Design 3 is described in Table 2, Table 3 and Table 4 respectively. The Central frequency and Capacitance measurement is shown in Table 5.

TABLE 5 CENTRAL FREQUENCY AND CAPACITANCE MEASUREMENT

DESIGN METHOD	Lithium Niobate ($LiNbO_3$) V_s – 3880 m/s		Zinc Oxide (ZnO) V_s – 3954 m/s	
	MHz	nF	MHz	nF
DESIGN 1 (300 μm)	F_0 = 6.466	C=0.4923	F_0 =6.59	C = 0.4830
DESIGN 2 (450 μm)	F_0 = 4.222	C=0.7539	F_0 =4.393	C = 0.7245
DESIGN 3 (600 μm)	F_0 =3.233	C=0.9845	F_0 =3.295	C = 0.9660

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Website: www.ijareeie.com

Vol. 6, Issue 2, February 2017

REFERENCES

[1] Saw Temperature Sensor On Quartz, Sergei Zhgoon, Senior Member, Ieee, Alexander Shvetsov, Ivan Ancev, Sergei Bogoslovsky,gennadiy Sapozhnikov, Konstantin Trokhimets, And Mikhail Derkach, Vol. 62, No. 6, June 2015.
[2] Performance Prediction And Sensitivity Analysis Of Saw Gas Sensors, Jinn-tsong Tsai1, Kai-yu Chiu2, And Jyh-horng Chou, Received July 28, 2015, Accepted September 1, 2015, Publication- September 18, 2015, Version,september 29, 2015.
[3] New Capabilities for Optimizing SAW Gas SENSOR, Vladimir I. Anisimkin and Enrico Verona, Vol. 48, No. 5, September 2014.
[4] Design And Analysis Of Saw Based Mems Gas Sensor For The Detection Of Volatile Organic Gases Staline Johnson, Dr. T. Shanmuganantham, Vol. 4, Issue 3, March 2014, pp.254-258.
[5] El Gowini M. M., Moussa W. A., A Finite Element Model Of A Mems-based Surface Acoustic Wave Hydrogen Sensor, Journal Sensors, vol. 10, pp. 1232–1250, 2010.
[6] Study Of The Acoustoelectric Effect For Saw Sensors ,Brian H. Fisher And Donald C.Malocha, Vol. 57, No. 3, March 2013.
[7] New Capabilities for Optimizing SAW Gas SENSOR, Vladimir I. Anisimkin and Enrico Verona, Vol. 48, No. 5, September 2014.