This work describes basic concept of chemical sensors based on surface acoustic wave (SAW). The aim is to depict basic physical concept and simulation rough draft for this type of sensors. By integrating a SAW measurement platform with a selective sensing layer, a desired chemical microsensor is constructed, which provides some of the functionality of an analytical instrument, but with extraordinary reduced cost, size, and power consumption.

The objective of this paper is presents gas sensors based on one-port and two-port interdigitated metal structures. The impulse response model is used for determination of IDT parameters and first order investigation, the transient analysis is performed on the devices to study the acoustic wave propagation and characterize the device in time and frequency domain. The effects of the various interdigital transducer (IDT) design, intermediate layer thickness and chemical sensitivity structure on the propagation characteristics is also investigated. Also, we present some results obtained from the device using automated measurement system for SAW oscillator frequency measurement.

**Keywords**: sensor, Gas sensors, SAW, IDT structure, measurement, oscillator.

1 INTRODUCTION

Surface acoustic wave (SAW) devices are microelectromechanical systems (MEMS) and as the name suggest, these waves travel very close to the surface of a piezoelectric substrate (to distance of one wavelength from the surface of the substrate). SAW’s utilise Rayleigh waves, named after Lord Rayleigh [1], which in 1885 studied and correctly analytically described the propagation of earthquake waves on earth’s surface. A mechanical wave is generated when an alternating electrical signal is applied to an interdigitated transducer (IDT) that is placed on top of a piezoelectric substrate. This mechanical wave propagates through or on the surface of the material, and it can be picked up and converted back into electrical signal by using another IDT placed in the path of wave propagation. Any changes in between the two IDTs will cause certain amount of attenuation and delay in the wave propagation and can then be correlated to the corresponding desired chemical element (which always has a certain amount of physical quantity) binded with the coated selective layer. And this is root idea of SAW device for sensing applications such as detecting physical, chemical and biochemical quantities.

SAW devices have been utilised in gas sensing applications since end of 70s [2], thus a lot of work has been done and in general, SAW sensors suffer from insufficient sensitivity and detection limit. However, we are looking to opposite direction, detect species of interest below the concentration levels and SAW sensors with reachable detection limits in the picogram range are almost ideal. In its simplest form, a SAW device appears as two comb-like metal structures deposited on a piezoelectric crystal surface (Figure 1) and chemical sensing is reached by detecting the mass loading when and thus perturbing the surface acoustic wave channel.

![SAW device structure](image)

**Figure 1**: SAW device structure [3]

2. INTERDIGITAL TRANSDUCERS (IDT)

Two pair of symmetrical interdigital transducer (IDT) - invented by White/Voltmeter in 1965 - are the most usually used design for generating and receiving waves by exploiting the piezoelectric effect of the substrate as illustrated in figure 2. Design is quite simple, just two sets of closely spaced metal electrodes on a piezoelectric substrate. SAW acoustic wavelength $\lambda_o$ is given by
$$\lambda_0 = \frac{v}{f_0}$$  \hspace{1cm} (1)

where $v$ is SAW velocity and $f_0$ is fundamental operating frequency. An electrode finger width is in a SAW IDT typically $\lambda f_0 / 4$.

$$\lambda_{SAW} = \frac{v_{SAW}}{f} = 2 \mu \text{m} \ldots (\sim 1 \ldots 10 \mu \text{m})$$  \hspace{1cm} (2)

The metallization ratio

$$\eta = \frac{h}{(h+p)}$$  \hspace{1cm} (3)

where $h$ is the electrode width and $p$ the gap between consequence electrodes - Figure 3.

The basic relation for SAW express that frequency shift is proportional to coupling coefficient, mass change and square of resonance frequency

$$\Delta f = -k f_0^2 \Delta m$$  \hspace{1cm} (4)

where $k$ electromechanical coupling coefficient, $f_0$, resonance frequency and $\Delta m$ mass change. For example, if we assume the area $1 \text{ mm}^2$ & $f_0 = 1 \text{ GHz}$, we will get $k f_0 \sim 10^7 / \text{kg}$, which implies that $1 \text{ ppm}$ of $f$ deviation, this is equal to resolution $0.1 \text{ pg}$.

Most utilized interaction in SAW sensor applications is relation of SAW and mass loading – in other words, response due to changes in area/mass (mass/area) on the device surface. In the limit of a thin film the sensor is mass loaded and a frequency shift that depends on the mass of the layer is found. The mass of the layer is determined from the Sauerbrey equation.

$$\Delta m = m_0 \Delta f / f_0$$  \hspace{1cm} (5)

and $\Delta f$ the frequency shift after deposition. It is known that,

$$\frac{\Delta \nu}{v_0} = -c_{\text{material}} f_0 \rho_s$$  \hspace{1cm} (6)

and thus, SAW incorporated in an oscillator loop

$$\frac{\Delta f}{f_0} = -c_{\text{material}} f_0^2 \rho_s$$  \hspace{1cm} (7)

$$\Delta f' = -c_{\text{material}} f_0^2 \rho_s$$  \hspace{1cm} (8)

where $c_{\text{material}}$ is specific material constant, $\rho_s$ density of substrate, $\Delta \nu$ is velocity shift, $v_0$ is basic SAW velocity.

The maximum frequency possible is determined by electrode width. At the centre frequency the electrodes have spacing $\lambda/2$, and width typically $\lambda/4$. Changes properties of chemical sensitive thin film perturb the mechanical properties of the wave propagation and its associated electrical field. Hence, this would result in changes in the velocity of acoustic wave propagation and its amplitude. In perturbation theory, these effects are described using the following equation [5]

$$\frac{\Delta \nu}{v_0} = \left( \frac{2h}{\lambda} \right) \left[ -\frac{\Delta \rho}{\rho} \left( \frac{A_x^2 + A_y^2 + A_z^2}{\rho v_s^2} \right) + \left( \frac{1 - \Delta C_{11}}{C_{11}} \right)^2 - 1 \right] \left( \frac{4 A_z^2 C_{11}}{C_{11}} \right)$$  \hspace{1cm} (9)

where $v_0$ represents the velocity of the SAW in the particular piezoelectric substrate, $A_x$, $A_y$ and $A_z$ the normalized mechanical displacements in the x-, y- and z-directions, respectively, $C_{11}$ and $C_{44}$ are the elastic constants of the film, $h$ the thickness of the thin film, $\lambda$ the wavelength of the SAW and $\rho$ is the density of the film [5]. The values of the above elastic constants and density for example for Palladium thin film are as follows: $C_{11}=190GPa$, $C_{44}=40GPa$ and $\rho=12,023kg/m^3$ [5].
3 OSCILLATOR CIRCUIT

SAW gas sensor testing can be performed using the oscillator circuit, Figure 4. The circuit used for realizing oscillator with commercially available one-port 434MHz SAW resonator can be seen on Figure 5. Single stage RF transistor amplifier has been used. The design uses surface mount components and the oscillators operate at 5V power supply. Tuning of the inductances and capacitors are crucial for the operation of these oscillators. In the one-port oscillator, the tank circuit L3, C3 and C4 are fine tuned by placing a short at the location of the SAW device [6] (in the Figure 5 represented by simplified universal equivalent circuit). The outputs of the oscillators was monitored by using a spectrum analyzer, but can be used also an oscilloscope and a frequency counter.

Figure 4: Oscillator block diagram.

Figure 5: Oscillator circuits with one-port SAW resonator device.

Figure 6 shows PCB with SAW oscillator circuits and fabricated SAW sensors, which is connected to 50Ω input of spectrum analyzer by SMA connector, impedance matching is done by 47nH air coil.

4 SAW STRUCTURES

Surface acoustic wave (SAW) sensors, which are sensitive to a variety of surface changes, have been widely used for chemical and physical sensing. All acoustic wave devices and sensors use a piezoelectric material (PVDF, quartz SiO₂, LiTaO₃, LiNbO₃, PZT) creates a mechanical stress. Piezoelectric acoustic wave sensors apply an oscillating electric field to create a mechanical wave, which propagates through the substrate and is then converted back to an electric field for measurement.

Two pair of symmetrical interdigital transducer (IDT) are the most usually used design for generating and receiving waves by exploiting the piezoelectric effect of the substrate as is illustrated in Figure 7.
The effects of the various interdigital transducer (IDT) design (one port or two port resonators, two port delay lines), intermediate layer and coating structure on the propagation characteristics is also investigated (see Figure 7 and Figure 8).

Figure 8: Model of one port SAW resonator and fabricated device.

5 RESULTS AND CONCLUSIONS

Also, a comparison is provided between the measured and simulated frequency response (see Figure 9). Results indicate that with increasing the gas concentration the wave velocity decreases and the attenuation of the wave is reduced and our methodology provides powerful tools to tune optimal design parameters.

Figure 9: Measurement setup.

Figure 10 demonstrates the spectral response of the SAW sensor for different concentration of acetone.

Figure 10 shows the spectral response of the SAW sensor for different concentration of acetone.

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