MEMS ALCOHOL SENSOR FOR SAFETY OF DRIVER IN AUTOMOBILES

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ABSTRACT

The objective of this paper is towards designing a new MEMS (Micro Electro Mechanical Systems) based alcohol sensor to detect the presence of alcohol in a driver. Alcohol impaired driving accounts for nearly one-third (31%) of all traffic-related deaths in the United States. Vehicle-based alcohol detection systems use technologies which are bulky, space occupying, requires skin contact and is less sensitive to low concentration of alcohol and so there is need for designing a robust alcohol sensor. Thus the prime reason for choosing MEMS based alcohol sensor is to reduce the size of existing sensor, thereby providing high sensitivity, high stability, non-invasive and non-obtrusive device. Two different configuration of MEMS Alcohol sensor has being designed; first SAW (Surface Acoustic Wave) Alcohol Sensor and secondly based on surface reaction consisting of micro pillar (reacting pillars). The design and analysis of these two configurations were performed in COMSOL Multiphysics 4.4 software. The simulated results for both sensors show the concentration of alcohol in breath. Thus the MEMS alcohol sensors are designed for safety purposes in automobiles.

Keywords: alcohol sensor, impaired driving, MEMS, SAW gs sensor, COMSOL,

1. INTRODUCTION

Impaired driving is the act of operating or having control of a motor vehicle while under the influence of alcohol to the degree that, mental and motor skills are impaired.

Every day, almost 30 people in the United States die in motor vehicle crashes that involve an alcohol-impaired driver. This amounts to one death every 51 minutes [13]. The annual cost of alcohol-related crashes totals more than $59 billion. In 2012, 10, 322 people were killed in alcohol-impaired driving crashes, accounting for nearly one-third (31%) of all traffic-related deaths in the United States. Each year, 1.3 million people die in car accidents [14]. India has the highest number of road accidents in the world, followed by China and the U.S., according to World Health Organization.

The basic principle of detecting alcohol in driver's breadth is when the breadth containing alcohol molecules react with the sensing element; there is change in physical phenomenon such as resistance, capacitance, current flow, conductivity etc. This change can be measured and hence the detection of alcohol can be confirmed [4].

A new and unique technique for more efficient alcohol detection system is Water Cluster Detection (WCD) which detects expired gas based on the principle that water clusters in breath are easily separated into positively and negatively charged ions by using an electric field [3]. Due to size of WCD sensor being pretty huge, it limits the application in automobiles.

A. Surface acoustic wave (SAW) sensor

They are a class of MEMS which rely on the modulation of surface acoustic waves to sense a physical phenomenon. The sensor transduces an input electrical signal into a mechanical wave which, unlike an electrical signal, can be easily influenced by physical phenomena. The device then transduces this wave back into an electrical signal. Changes in amplitude, phase, frequency, or time-delay between the input and output electrical signals can be used to measure the presence of the desired phenomenon [9].

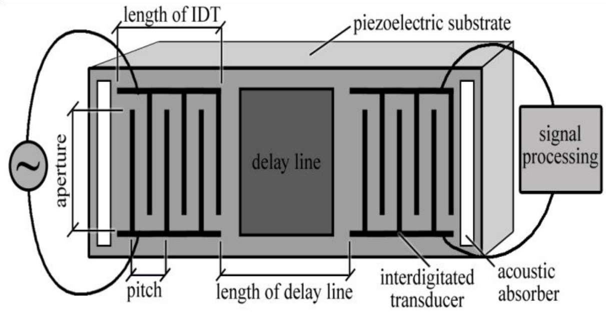

Figure-1. Surface acoustic wave sensor interdigitated transducer diagram.

The basic SAW device consists of a piezoelectric substrate, an input interdigitated transducer (IDT) on one side of the surface of the substrate, and a second, output IDT on the other side of the substrate. The space between the IDTs, across which the SAW will propagate, is known as the delay-line because the signal, which is a mechanical wave at this point, moves much slower than its electromagnetic form, thus causing an appreciable delay [9].

As the characteristics of the SAW can be modified by changes in the surface properties of the device substrate, sensors can be designed to quantify any phenomenon such as mass and chemical reaction, which alters these properties [8], [9], [10].

B. Chemical reaction based alcohol sensor

The second configuration of alcohol sensor contains an array of micro pillars. The curved side of the pillars are coated with an active material that allows for the selective adsorption of analyte species in the sample stream i.e. alcohol molecules in breadth. The adsorbed species produce a signal that is dependent upon the local concentration at the pillar surfaces.

It uses Surface Reactions physics interface, the Transport of Diluted Species physics interface, and the Laminar Flow physics interface available in COMSOL Multiphysics 4.4 [10].

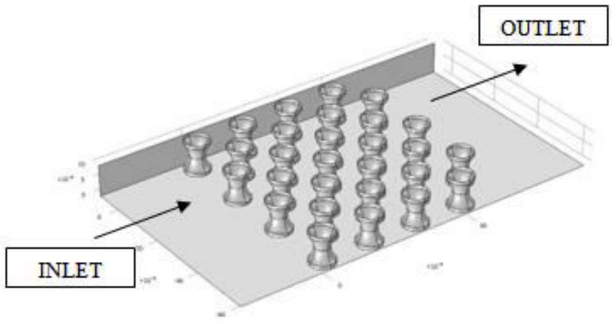

Figure-2. Basic diagram showing array of reacting micro pillars.

2. EXISTING SYSTEM

Vehicle-based alcohol detection systems use various forms of technology designed to detect the presence of alcohol in a driver. There exist systems which are designed to measure the amount of alcohol present in the driver referred to as the driver's blood alcohol concentration (BAC) [1]. The various technologies used in vehicles are explained below.

A. Breath sample analysis

A person's BAC can be determined accurately by measuring alcohol presence in a breath sample. It uses the same fuel cell technology as many evidential breathe test devices. All breath alcohol sensors require the driver's active involvement to provide a breath sample. Accurate measurement of BAC in breath requires a deep lung sample of breath; mouth or bronchial breath does not necessarily provide an accurate measurement of BAC [1].

B. Tissue spectroscopy

A person's BAC can be determined accurately using light reflected from capillaries in the skin. This device requires a person being tested to place his forearm on a lighted sensor pad. The pad contains a spectroscope which measures the amount of near-infrared reflected light of different wavelengths from the capillaries in the skin and calculates the person's BAC. It requires multiple readings over a couple of minutes [2].

C. Distant spectrometry

It is similar to tissue spectrometry, except that no skin contact is required. Infrared light is transmitted toward the subject from a source that receives and analyses the reflected and absorbed spectrum, to assess alcohol concentration in the subject's tissue or exhaled breath [2].

D. Transdermal perspiration measurement

A portion of any alcohol present in the body appears in perspiration and is used to detect the presence of alcohol vapor exuded from the skin. The device is strapped to the ankle to monitor alcohol consumption in persons. Transdermal measurement of alcohol vapor appears less promising than tissue spectroscopy because it does not correlate well with BAC measurements made from blood or breath. While transdermal alcohol measurement devices could be placed in a vehicle's steering wheel, this technology faces significant challenges in accurately measuring BAC [6].

E. Eye movements

Alcohol affects some eye movements. Measuring eye movements requires in- vehicle cameras or similar equipment. While this approach may prove to be technologically feasible, it will take significant technological advances and research efforts to get to a practical and acceptable technology in a reasonable timeframe [6].

3. PROPOSED SYSTEM

The main focus of the design of MEMS Alcohol sensor is to sense even the smallest concentration of alcohol in driver's breadth. This paper aims at design of alcohol sensor with two different configurations, SAW Alcohol Sensor and sensor based on Chemical Reaction.

A. SAW alcohol sensor

SAW sensor consists of an interdigitated transducer (IDT) etched onto a piezoelectric $LiNbO_3$ (lithium niobate) substrate and covered with a thin polyisobutylene (PIB) film. PIB film has the ability to hold air. The mass of the PIB film increases as PIB selectively adsorbs CH_2 Cl_2 (dichloromethane, DCM) in air. DCM is an organic solvent which can easily dissolve alcohol. This causes a shift in resonance to a slightly lower frequency [7].

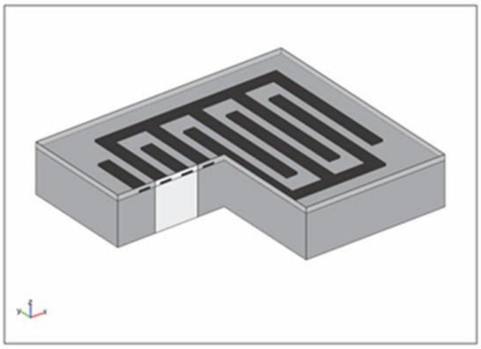

Figure-3. SAW gas sensor, showing the IDT electrodes (in black), the thin PIB film (light gray), and the LiNbO3 substrate (dark gray).

The materials used for SAW sensors have the following specifications. For $LiNbO_3$, the density is 4647 kg/m^3 (elasticity matrix, coupling matrix and relative permittivity matrixes of $LiNbO_3$ were entered). Then for PIB, Young's modulus is10 GPa and Poisson's ratio is 0.48.

Adsorption of DCM gas is represented as a slight increase of the density of the PIB film. Partial density of DCM in the PIB film is then calculated as

$$\rho_{DCM,PIB} = KMc \tag{1}$$

where,
K = 101.4821 =air/PIB partition coefficient for DCM,
M = 0.08493kg/mol= molar mass,
c = 100. 10^{-6}. p/ (RT) = concentration of PIB in air.

Any effects of the DCM adsorption on the material properties other than the density are neglected.

B. Design of SAW gas sensor

The substrate ($LiNbO_3$) is designed with width of 4μm and a height of 22.5 μm. The PIB layer is designed with a width of 4μm and a height of 0.5 μm. Two electrodes with width of 1μm and height of 0.2 μm each was considered for the simulation. A slice of the geometry is removed to reveal the modelled unit cell (in white). Refer Figure-3. The sensor was exposed to 100 ppm of DCM in air.

C. Sensor based on chemical reaction

Sensor contains an array of micro pillars as shown in Figure-2. The inlet and outlet are defined for flow of air along with alcohol molecules. The curved sides of micro pillars are coated with an active material or sensing material, thus allowing adsorption of alcohol molecules onto the pillars. Adsorbed species produce a signal that is dependent upon the concentration at the pillar surfaces.

D. Design of sensor based on chemical reaction

Alcohol molecules (P) can adsorb and desorb from surface sites (S) on the micro pillar surfaces according to

$$P + S \longleftrightarrow PS \tag{2}$$

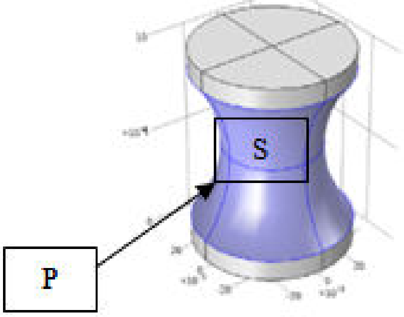

Figure-4. Curved structure of micro pillar with alcohol molecule P and surface site S.

The rate of adsorption is given by

$$r_{ads} = k_{ads}\, c_P \tag{3}$$

The desorption rate is linear in the concentration of surface adsorbed species c_{PS}:

$$r_{des} = k_{des}\, c_{PS} \tag{4}$$

where c_P is the concentration of P in the stream.

Adsorption and Desorption of alcohol molecules at the active pillar surfaces give net flux, Np

$$Np = -r\text{ads} + r\text{des} \tag{5}$$

Thus the mass flux and rate of absorption depends on concentration of adsorbed surface species. Table1 shows the parameters used for simulation [12].

Table-1. Adsorption governing constants.

Name	Expression	Description
c_0	400[mol/m^3]	Initial concentration
k_ads	0.01[m/s]	Forward rate constant
k_des	0.5[mol /(m^2. s]	Backward rate constant
Gamma_s	1000[mol/m^2]	Active site concentration
D	5 x 10^{-9}[m^2/s]	Gas diffusivity
u_in	2 x 10^{-4}[m^2/s]	Inlet velocity

4. SIMULATION RESULTS

The design and simulation of MEMS alcohol sensor were done using COMSOL Multiphysics® 4.4. The simulation of SAW Alcohol Sensor and sensor based on chemical reaction is performed.

A. SAW alcohol sensor

The presence of the aluminum IDT electrodes and the PIB film cause the lowest SAW mode to split up in two eigen solutions, the lowest one representing a series resonance, where propagating waves interfere constructively and the other one a parallel ("anti-") resonance, where they interfere destructively.

These two frequencies constitute the edges of the stopband, within which no waves can propagate through the IDT.

The resonance and anti-resonance frequencies evaluate to approximately 839 MHz and 849 MHz, respectively. Figure-5 shows the corresponding SAW modes with the electric potential distribution characteristics for these solutions.

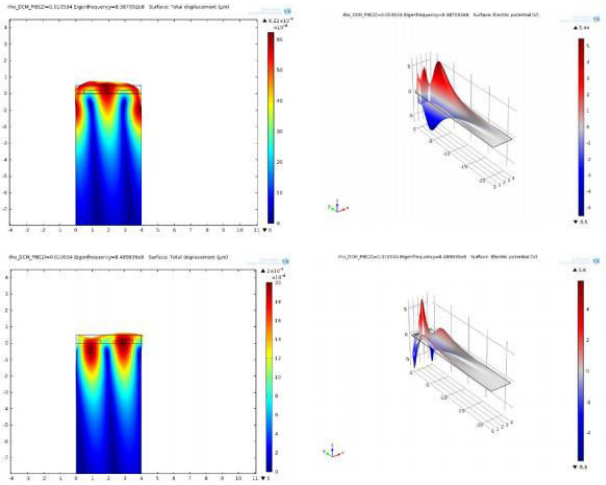

Figure-5. Simulation results for SAW Sensor showing total displacement and electric potential distribution for Eigen frequencies 8.387092e8 and 8.489836e8.

Exposing the sensor to a 100 ppm concentration of DCM in air leads to a resonance frequency shift of approximately 200 Hz downwards. This is computed by evaluating the resonance frequency before and after increasing the density of adsorbed DCM to that of the PIB domain.

Figure-6 illustrates the relation between the Eigen frequency and the density of PIB. It can be seen from the graph that when the density of PIB is zero, no Eigen frequency is generated. But when the density of PIB increases due to alcohol molecules absorbed by DCM, Eigen frequencies are generated.

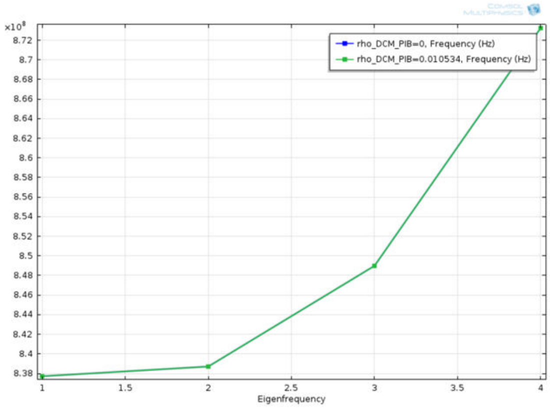

Figure-6. Graph showing relation between Eigen frequency and density of PIB.

B. Sensor based on chemical reaction

The Transport of dilute species physics of COMSOL helps us to simulate the chemical reactions between the active material coated onto the micro pillar and the alcohol molecules in air as inflow [12].

The reaction between the sensing layer and the gas analyte is provided by a set of equations and constants. The governing constants are provided in Table-1. The surface reaction rate and the inlet velocity profile equations govern the chemical reaction. The surface reaction rate is defined by

$$R_{s,cs\_P}=r\_ads-r\_des \qquad (6)$$

Figure-7 shows the concentration of the alcohol molecules, P, in the air stream and Figure-8 depicts the relative coverage of surface adsorbed species, PS, as the air passes through the array of micro pillars.

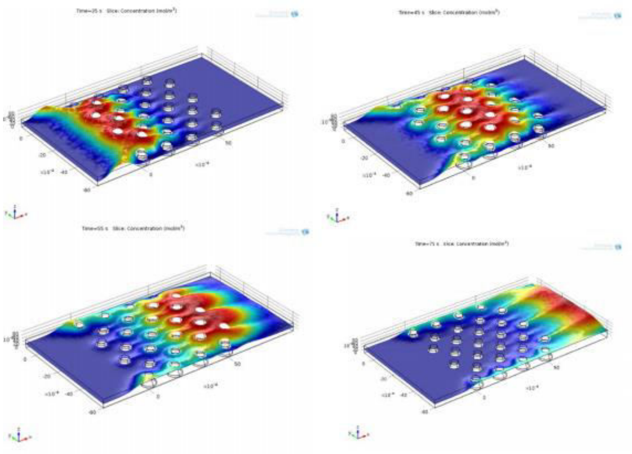

Figure-7. Concentration distribution in the alcohol molecules, P, at t = 35, 45, 55,75seconds.

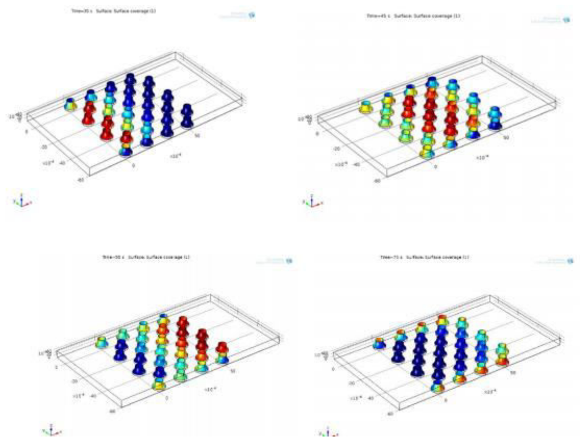

Figure-8. Surface coverage of adsorbed species, PS, at t = 35, 45, 55,75 seconds.

The velocity distribution of the flow field will cause pillars near the wall to reach their maximum adsorption level at a later time compared to pillars in the center of the stream. Pillars near the wall will also take longer to release adsorbed analyte. The position of a pillar in a row also has an effect on the maximum adsorption level, and the time at which it is reached. This effect is highlighted in Figure-9.

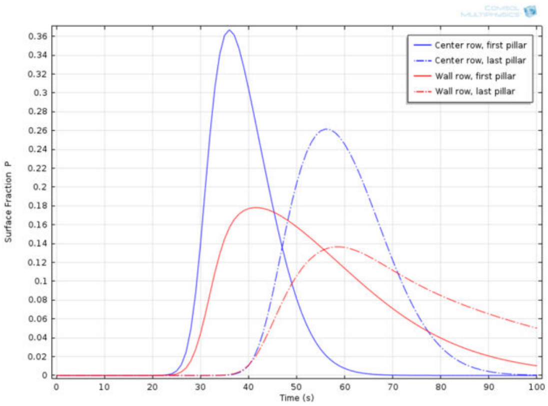

Figure-9. Average fractional surface coverage of adsorbed species, PS.

5. CONCLUSION AND FUTURE WORK

The results obtained from the simulation validate the working principle of the sensor. Exposing the SAW sensor to 100 ppm concentration of DCM in air leads to a resonance frequency shift of approximately 200 Hz downwards. Subtracting the new value of density of PIB from the previous value shows that the Eigen frequency with gas exposure is lower approximately 200 Hz. Thus the resonant frequency of SAW Gas Sensor was investigated.

The air flow containing alcohol molecules will cause pillars near the wall to reach their maximum adsorption level at a later time compared to pillars in the center of the stream. Pillars near the wall will also take longer time to release adsorbed molecules. These geometrical effects will cause the sensor signal to become relatively diffuse.

The output of proposed alcohol sensor configurations can be integrated into the Electronic Control Unit (ECU) of the automobile which can stop the engine so as to ensure the safety of driver. This can be considered as the future work planned.

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