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Micro Gas Sensors for Detection of Acetone for Non-Invasive Diabetes Monitoring

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Abstract:

The Metal Oxide Semiconductor sensor has the ability to detect volatile organic compound gases in human exhaled breath as a result of metabolic processes and to calculate diabetes levels in a non-invasive manner. In comparison to non-diabetic people, diabetic people have peak acetone levels in exhaled air. One can measure the degree of diabetes by calculating the concentration of acetone in a volatile organic compound. Using COMSOL multiphysics software, we were able to model and simulate an acetone-based SnO2 gas sensor by solving Poisson's equations under related boundary conditions of mass, heat, and electrical transitions. Using COMSOL multiphysics software, we were able to model and simulate an acetone-based SnO2 gas sensor. An exposure model was used to show the necessary acetone, a heat transfer model was used to determine the reaction temperature, and an electric model was used to complete the simulation.

Keywords :- potential tool; non-invasive; diabetes; MOS sensors;

1.Introduction

Another use for metal oxide semiconductor (MOS) sensors is for diagnosing various types of chronic metabolic problems based on a person's breath study. They have over 5,500 volatile organic compounds (various exhaled). To understand diabetes, you must measure acetone levels in the blood. Some diabetics have a distinctive breath, usually smelling of acetone. Diabetes type-1 and type-2 complications are also to blame It's recognised as ketoacidosis (DKA). which needs to be addressed immediately When anyone has diabetes, their body does not produce enough insulin or the insulin that they produce is not absorbed effectively. Insulin normally makes the cell break down glucose (C6H12). Generally, in people with diabetes, insulin is not made by the pancreas, because they would use fat as an energy source. The breakdown of fats into usable energy occurs in the course of ketosis. whenever this cycle repeats itself. Acetone is one of the substances the liver creates in ketosis. When the fat is decomposing, the breath can have a powerful, unpleasant scent of acetone. Concentration of acetone in breath is linked to sugar levels Type 1 and 2 diabetics have a greater acetone spectrum than those who do not have the disease. For healthy individuals, acetone concentrations range from 300 to 900 ppm which may vary depending on several factors. People with diabetes can need an invasive tests for the level of acetone in their breath. This means drawing a small amount of blood using a sharp, needle. Additionally, it causes much discomfort, is costly, and is completely impractical for constant surveillance. exhaled breath analysis offers a fast and non-invasive screening test for metabolic issues.

Metal oxide semiconductor (MOS) The use of an intrusive approach to check blood sugar relies on a lot on the sensor helping in a non-invasive process Many other breath analysis methods include various gas chromatography/mass spectrometry technologies (GC/MS), such as choose ion-flow time-of-of-flight mass-selected gas chromatography (MOS) and chemical sensors. Additives often need more expensive facilities and are time-consuming to maintain. Among the most common sensor methods, the metal oxide method has evolved to be used for continuous use and practicality. minimal capacity, rapidly deployable, efficient scale, low power, minimal expense, fast recovery period Studies have emphasised portability, power usage, and identification limits recently.

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Here is a detailed information on solid-state gas sensors utilising different sensing materials including metal oxides, coval semiconductors, polymers, electrolytes, and salts as active layers: Any of these semiconductor oxides, metal oxides, and/metal hydrides have been used as chemires in the production of semiconductor chemical sensors over the last few decades. Despite having a highly sensitive metal oxide gas sensor, the need for improved working temperature is still strong in the electronics industry reduced and reduced metal sensors The oxide layer is employed in gas-resistance sensors to detect target gases It depends on fabrication techniques like hydrothermal, thermal evaporation, physical-v deposition, chemical-vapvap, or sol–gel, which can provide 500nm to 30μm of sensing layer thickness. Thickness of layer decreases below 20 m by means of the sol-gel process [18,20].

2. Selection of material

Most of semiconducting metal oxides such as s ZnO, SnO_2, ZrO_2, TiO_2 have been investigated experimentally. Among them Sno2 is reliable used as gas sensing material in MOS gas sensor because of its low cost, long-life , good reproducibility, high efficiency, cheaper and easy availability. SnO_2 is n-type semiconductor with energy band gap of 3.6eV. Due to tetragonal crystalline structure and high mobility of charge carrier concentration, SnO_2 used as a suitable gas sensing material and it also shows good sensing response. It is a good agent for thermal stability, chemical stability, good ability to absorb oxygen ions[21,22]. SnO_2 have been synthesized in different morphologies such as nanowire, mesoporous materials hollow sphere and coral-like porous structures for improving gas sensing properties[23].

3. Process flow

The operating theory of a reversible flow of charge in the metal oxide layer caused by the exposure of gas molecules is metal oxide sensor. When the sensing element is heated by the heater, the gas sensor's response would be an increase in resistance. when the MOS sensor is in air, it would be contaminated with an oxygen like substance then the oxygen molecules can get involved Emissions of the sensor's sensing feature trigger this unwanted reaction flow of electrons. There is no detectable variation in the sensing factor, or possible distinction. As a result, there is no sensor production at the electrodes. communication with the reduction gases such as acetone or methanol may be hazardous to the sensitive electronic sensing portion of a MOS sensor An acetone molecule is now takes the position of the acetylene one. When the acetone reacts with the sensing product, the mixture changes colour. Once the acetone molecule removes the electrons from the sensing portion of the MOS sensor, the signal decreases. Another benefit of the electrodes in sensing elements is that they can detect variation of electrical resistance. Then the production of the gas diffusion element is proportionate to the concentration of acetone in the region.

3.1 Sensor architecture

The sensor consists of five layers 1) substrate 2) heater 3) insulating layer 4) metal electrode 5) sensing layer

3.1.1) Substrate

Phase takes place on the substrate. When you use the telephone, it turns mechanical behaviour into electrical output. The substrate is a single piece of silicon sliced into a single crystal. Substrate products such as silicon, quartz, gallium arsenide, and arsenic sulphide may be used. the underlying material is the sensor and supplies mechanical and thermal support for the substrate The layer has a dimension of 0.8*0.05mm to 0.0.8 µm Aluminum's freezing point is less than 14,000 degrees Celsius. Stabilizing silicon with ammonia preserves the usefulness of this material even at elevated temperatures.

3.1.2) Heater

To detect acetone in breath, the heater is critical to the gas sensor. The DC voltage is used to detect acetone at a required temperature of 3,500 to 3,800°C (64 to 401.5°F) with the Dimensions 0.06 to 0.02 [micromm] a trace-

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gap of less than half a micrometre In order to detect the presence of acetone, the heater has a consistent distribution of temperature for the sensing substrate. Platinum is used for warmth. The main benefits of platinum are lower density, higher conductivity, excellent specific heat power, and excellent ductility. Platinum is both malleable and ductile, and thick. It has a better basic heat and the ability to heat up well

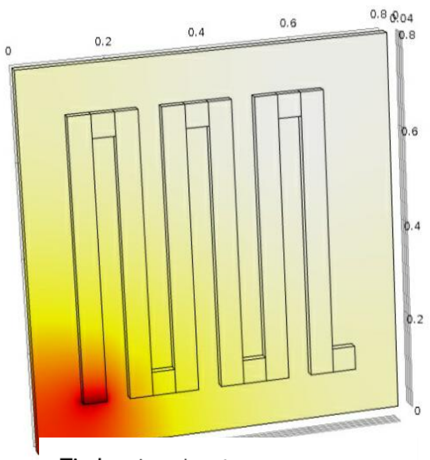

Fig.1 . micro heater

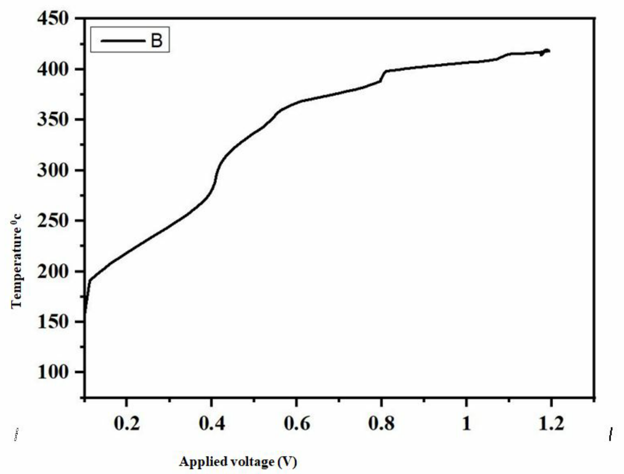

Fig.2 . variation of temperature vs voltage

3.1.3) Insulating layer :-

They are an insulator that keeps the electrodes apart from touching the radiator. Silicon dioxide has lengths of 0.6 µm to 0.01 microns used as an insulating film and a thickness of 0.6 µm.0, 0.6.0060 µm in silicon. The support layer helps to ensure a uniform temperature with an insulation layer being used for the heater. It is extremely desirous to keep the impedance losses to a minimum. The insulation's thickness can directly affect the heater's thermal conductivity.

3.1.4) ELECTRODE

Electrodes are made of platinum with the dimension of 0.6*0.01*0.05 µm. The purpose of the electrode is to collect the voltage developed across the sensing layer. It has better electrical conductivity with 9.66 *106 s/m. The change in resistance in electrode is directly depends on gas observe on sensing film.

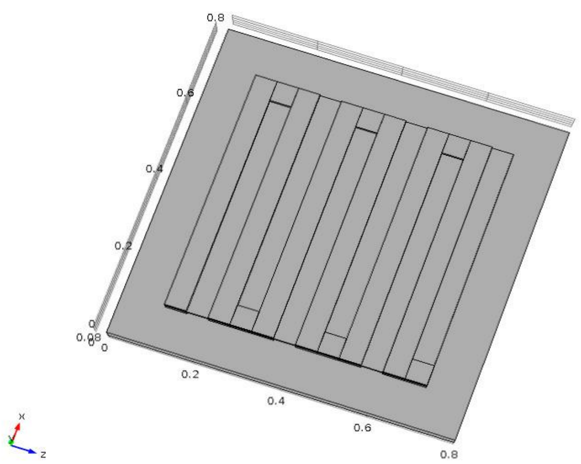

Fig.3 . voltage distribution across the electrode

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3.1.5) Sensing layer

In the chemireceptors, an active layers are applied to two or more electrodes, which determine the shift in electrical resistance of an oxide's concentration. Ordinarily, the content contained in this layer becomes less mobile. the dominant charge carrier and gas form influence whether or decreases the oxide resistance. The resistivity of the applied substrate determines how the sensor reacts. According to different methods, reaction may be represented as one of various numbers. creative gas (Rg) (Rg). The reaction for an n-type compound is written as an oxidation reaction. For the p-type selenium, it's the same.

compiled gas sensors react to n-type or p-type sensors, respectively, to standardised responses. Sensor tolerance when working in the presence of oxygen is referred to as "Ra", and when working in the presence of a mixture of acetone gas is known as "Rg". As the concentration of acetone is increased, the resistivity of a p-type heterojunction computes. to simplify the assignment of n- and p-type gas sensor response evaluation The response from an illegal alien refugee who said "there's nothing left for me here in this country" after telling her storey in front of the United Nations General Assembly and that he and that all the families are planning to move on his account of.

Type of sensing element	**Oxidization gas**	**Reduction gas**
P-type	Resistance is minimum	Resistance is maximum
N-type	Resistance is maximum	Resistance is minimum

Table 1 . Classification of sensing element

3.3) Testing chamber

The cylinder is designed to test the sensor while the experiment is conducted in the absence of air or an organic solvent. The chamber is hermetically sealed and surrounded by an inert gas. The cylinder is composed of an in two parts, an inlet and an outlet. A steady pressure of 10 kilopascals is used to inject the gas into the cavity, with a temperature of 100 degrees Celsius. The gas and the sensing factor get into touch with each other. In the presence of air, sensors can have a useful purpose, but are not functional; in the absence of air, they are defunct.

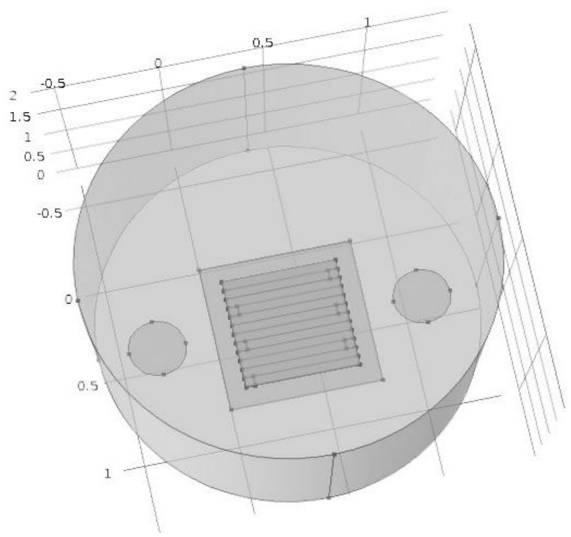

Fig.4. Testing chamber

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4) Simulation analysis

Developed in COMSOL Multiphysics. The sensor was created in a 3D CAD model using the COMSOL software, which integrates mechanics, geometry, and material modelling. a multi-platform solver, FEA and finite element analysis applications We apply four different theories of physics to analyse the system, including heat transfer in solids, current-carrying and dilute spice transport. To find out how the current is related to voltage in the presence of a sensor, we use heat transfer in solids. the laminar flow and diffusion are methods of exposing the sensor.

in a single flow of fluids, the pressure and velocity fields are calculated The laminar flow is calculated using the Navier-Stokes equation and the momentum conservation equations. If the flow depends on Reynolds number, you must first estimate Reynolds number. The flow stays laminar as long as the Reynolds number is below the critical amount. If you put more energy into the waves, they can rise and shift about. stationary and time based flows are made possible by laminar flow

$$\rho \frac{Du}{Dt} = -\nabla p + \rho g + \eta \nabla^2 u \qquad \text{Eq(1)}$$

the adjustment of species in a solvent Fick's rule of diffusion is used to describe the motion of diluted animals. The interface computes diffusion and transport by means of convection in one dimension, two dimensions, and three.

4.1) Heat transfer by solids

To an extent, the volume of heat is dictated by how quickly the heater transfers or radiates to its surroundings. In this instance, thermal condition is described as a situation in which heat is transmitted from the heater to the gas sensing sheet. the heat that is gained or lost by the passage of electrons in a body, and by their physical collisions with particles heat transfer in a substance is inversely proportional to the temperature differential.

$$q^n = -k\nabla T \qquad \text{Eq(2)}$$

where k, T, and q″, are conductivity of material, temperature, and flux density respectively. The Fourier's law, then, can be written as

$$q^n = -k\{i\frac{dT}{dx} + j\frac{dT}{dy} + k\frac{dT}{dz}\} \qquad \text{Eq(3)}$$

Heat flux can be rewrite in the direction of n

$$q_n^n = -K\frac{dT}{dn} \qquad \text{Eq(4)}$$

So the total heat flux from Fourier's law can be rewritten as

$$q^n = iq_x^n + jq_y^n + kq_z^n \qquad \text{Eq(5)}$$

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Heat through convection and radiation transfers to the air around the object as well as to the sides of the device. The Neumann equation of heat transfer is considered to be an adequate first approximation to heat transfer in the most general case

$$q = q^n A = hA(T_a - T_b) \quad \text{Eq(6)}$$

Where, q, q-f, A, and Ta, and T are heat flow, heat flux, surface heat coefficient, and surface temperature, and where qTbA and Tb are the transferred heat, the heat transfer, and transferred temperature, respectively. Of heat flow in thermal radiation, electromagnetic waves are the form of waves. According to the Stefan-Boltzmann equation, radiant heat is:

$$q = q^n A = \epsilon\sigma A\sigma T_s^4 \quad \text{Eq(7)}$$

where q, q″, A, ε, σ, and Ts are heat transfer, heat flux, surface area, emissivity coefficient, Stefan-Boltzmann constant, and surface temperature, respectively.

4.2 Electric current

For devices at greater skin depth, the electric field, potential, and current propagation are performed in the virtual space. It depends on Ohm's law to determine electric properties are commonly used in stationary, frequency-domain, time-domain, and conducted media research.

$$\nabla . J = Q_i \quad \text{Eq(8)}$$

$$j = \sigma E + j_e \quad \text{Eq(9)}$$

$$E = -\nabla v \quad \text{Eq(10)}$$

σ is **conductivity** of a material,
E is the applied electric field,
J is the electric current density at a point.

5) Boundary conditions: In simulation of MOS gas sensor the boundary conditions are flexible at the top of active layer and fixed type at the bottom of layer. There are three types of boundary conditions are applied to device these are mass transfer equations, the heat transfer equations, and the electrical equations

5.1) **The boundary condition of expose acetone :-** There is no slip on the wall-side in the chamber. the boundary condition due to the slip is given as

$$U_T = 0 \quad \text{Eq(11)}$$

where U_T is a tangential velocity.

The boundary conditions of chamber due to the pressure of inlet and outlet gas respect is defined as

$$\{p_{inlet} = 0 p_{outlet} = 0$$

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5.2) The electrical boundary conditions for the active layer: The sensing layer of the sensor is electrically insulated from the surroundings; therefore, the boundary condition for the current density of the sensor can be described as

$$n.j = 0 \qquad \text{Eq(12)}$$

6) Results

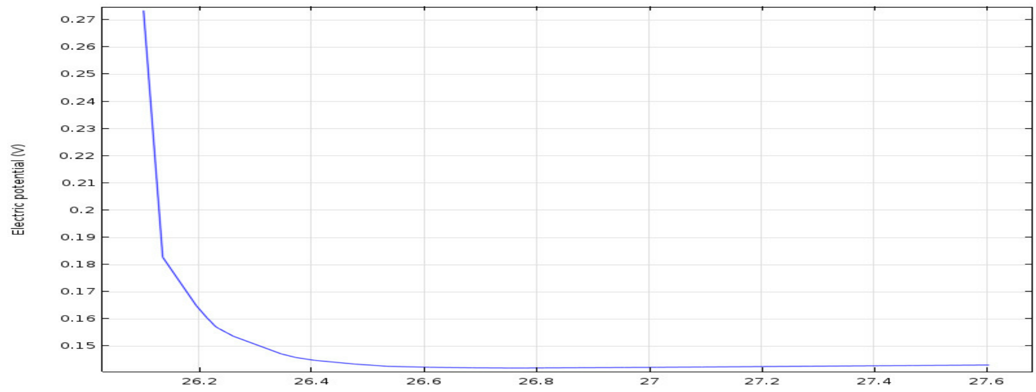

Fig 5 :- The voltage- concentration graph when exposed to air

. We use Sno_2 is sensing element in gas sensor. As SnO_2 is n-type sensing layer, it is sensitive to reduction gas and it requires some amount of temperature. The heater is developed in meander shape to produce required temperature of 350^0c - 380^0c to sensing element. when the senor is exposed to oxygen(air)O_2 in chamber at 380^0 approximately. The sensing element will become contact with air, as air is oxidation gas, it abort the flow of electrons between the electrodes in sensing element. So that, we observe that there is drop in potential across the electrode in sensing element. When the sensor is exposed to air.

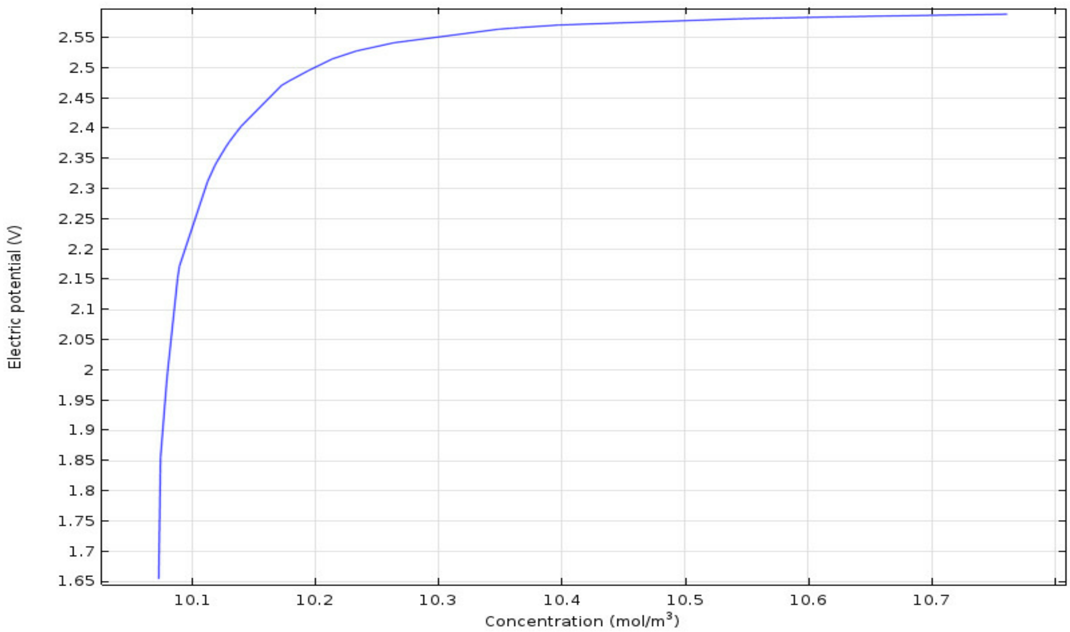

Fig 6 :- The voltage- concentration graph when exposed to acetone

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The sensor is immersed in acetone, or in the same state. On a lower consecration of acetone (10 mole/m^3), the voltage was found to be applied to the electrodes. The voltage around the electrodes goes up as the acetone content rises.

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