Application of MQ-138 Semiconductor Sensor for Breath Acetone Detection

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Abstract. A new application of MQ-138 semiconductor sensor for breath acetone detection is proposed in this work. MQ-138 semiconductor sensor was integrated to a system which consists of three blocks. This system offers benefits such as portable, fast and easy to operate. Experiments with breath acetone samples from both diabetes and nondiabetes patients validated the accuracy of this system. Based on the measurement results, it was found that as the sensor output voltage increased, the higher blood glucose values measured which means it has been proven that sensor readings of MQ-138 sensor has linear relation to the breath acetone. Therefore, the proposed system has a potential to be used for breath acetone detection in diabetes patients as a new application of MQ-138 semiconductor sensor.

1. Introduction

Metal oxide semiconductor based gas sensors are readily available commercially and has been widely applied for monitoring flammable as well as toxic gases in domestic and industrial environment [1,2], detection of hazardous volatile organic compounds (VOCs) [3], lung cancer detection [4]. There are many types of metal oxide semiconductor based gas sensors that shows gas sensitivity under suitable condition. However, sensors with tin dioxide (SnO₂) as sensitive material are widely used such as MQ-138 [5,6].

MQ-138 semiconductor sensor is one of the amongst metal oxide semiconductor based gas sensors which has high sensitivity to Acetone, Toluene and Formaldehyde. Besides, it has some advantages as gas sensor such as wide detecting scope, fast response, good stability, long lifetime, and simple drive circuit [6]. MQ-138 semiconductor sensor has been applied for sensor array in E-nose system to recognize gases and odors [7-9], food analysis [10]. However, this sensor has not been found in a single sensor system to detect specific gases or odors. Thus, a new application as a sensor system of MQ-138 semiconductor sensor to sense particular gases or odors is highly expected.

On other hand, acetone is one of the amongst VOC which is known as a product obtained from fatty acid metabolism and act as an important biomarker for diabetes detection [11]. Acetone concentration can be as high as 25 μmol/L (560 ppm) or even >1000 ppm in diabetes patients [12]. Therefore, the aim of this work is to produce a device for breath acetone detection as a new application of MQ-138 semiconductor sensor.
2. Experimental

In this section, the structure of the system used to collect and measure breath acetone will be explained, followed by the key part of the device. The next step, how breath acetone is measured in diabetes and non-diabetes volunteers will be described as well.

2.1. Structure of the Device

Figure 1 shows the design of the proposed system whose main framework is shown in Figure 2. It composes of three blocks namely input, process and output block. The input block consists of MQ-138 sensor in a testing chamber, the process block consists of arduino UNO while buzzer and LCD act as the output block.

Figure 1. Design of the proposed device structure.

Figure 2. The main framework of the proposed system.

The testing chamber consists of an input valve and gas room which breath acetone is drawn into it. The gas room is PLA chamber with MQ-138 sensor embedded into it which is connected to sensor
system. When the sensor is on contact with gas particles, the sensors resistance will change. Sensor resistance is measured by a voltage divider circuit and transformed into raw voltage signals as the sensor output value. In this case, MQ-138 sensor is already in the form of sensor module which has a working voltage value of 0-5 V and accuracy of the reading has reached standard value thus it does not require any reinforcement. As a result, the sensor output value can be directly sent to arduino UNO using I2C communication.

In the operation, when the system detect the gas particles drawn through input valve into gas room and indicated by the increasing of output voltage of the sensor, the buzzer will go off as an indicator that the system starting to work. After seven seconds, the buzzer will stop the beeping and within 30 seconds the system will send the ADC value data to the LCD and displayed on the screen. After that, the buzzer will reactive as a notice that the sensor requires recovery.

2.2. Clinical Testing

The clinical testing was done to see the performance of MQ-138 semiconductor sensor to detect breath acetone by exposing the sensor to the exhaled breath of diabetics and nondiabetics. The clinical testing was done by a few requirements. First, the volunteer attended the hospital in the morning after an overnight fast or at least for 4 hours. Second, each volunteer was asked to exhale their breath into the testing chamber using a sterile pipe for 7 s. It was repeated for ten times, and the average value of sensor reading was plotted. Finally, for the comparison, each volunteer was also tested using a glucometer to know their blood glucose value.

3. Result and Discussion

The concentration of breath acetone can indicate metabolic products of diabetes since diabetes is a disease caused by increased blood ketones which the gas-phase acetone in the blood equilizes with alveolar air (exhaled breath) through the alveoli [12]. In addition, it has been studied extensively and shown to be correlated with blood glucose. Medical reports showed that plasma acetone has been proven to be linearly related to breath acetone [13] and has a quantitative connection with blood glucose levels [14].

It is asserted that the blood glucose value of diabetes patients is up to 140 mg/dl and for nondiabetes patients is below 140 mg/dl. As considering this, the sensor output voltage values and blood glucose values that were measured by glucometer are compared.

![Figure 3. Sensor readings on nondiabetic and diabetic volunteers](image-url)
The MQ-138 semiconductor sensor works based on the interaction between the gas particles or in this case breath acetone with the sensor surface resulting in a change in the sensor output voltage. Figure 3 shows the sensor output voltage versus blood glucose value of nondiabetes and diabetes patients. It is clearly seen that MQ-138 sensor readings show the linear output voltage value to the blood glucose value. As the blood glucose value rises, the sensor output voltage increases as well which means they have a linear relation. Thus, it can be concluded that sensor readings of MQ-138 sensor are linearly related to breath acetone. It essentially means that the higher concentration of acetone, the higher resulting output voltage of MQ-138 sensor. Conversely, the lower concentration of acetone, the lower resulting output voltage of the sensor.

MQ-138 semiconductor sensor was fabricated using SnO$_2$ as its sensitive material. Generally, the gas-sensing mechanism of SnO$_2$ which is a n-type oxide semiconductor gas sensing material based on the change in electrical conductivity caused by the chemical interaction of gas molecules with the surface of sensing material [15-19]. This oxygen molecules such as O$_2^-$, O$^-$ or O$_2^-$ affect the resistance of SnO$_2$ under air atmosphere. In normal air, these oxygen molecules capture electrons from the conduction band of SnO$_2$, then chemisorbed oxygen ionic species adsorbed on the surface of the sensing element as shown in this equation below [17]:

\[
\begin{align*}
O_2 \text{(gas)} + e^- &\leftrightarrow O_2^- \text{(ads)} \quad (1) \\
O_2^- + e^- &\leftrightarrow 2O^- \text{(ads)} \quad (2) \\
2O^- + e^- &\leftrightarrow O_2^- \text{(ads)} \quad (3)
\end{align*}
\]

Due to this process, the concentration of electrons will be decreased and a depletion layer or thick space-charge layer will be created at the surface and barrier height will increase which leads to a high resistance of the sensor. When the sensor are exposed to breath acetone, the ionized oxygen species release the captured electrons back to the conduction band, leading to a thinner space-charge layer and lower potential barrier thus causes an increase in the conductivity and the decrease of resistance. The reaction between breath acetone and ionized oxygen species may take place as [17,19]:

\[
\begin{align*}
\text{CH}_3\text{COCH}_3 \text{(gas)} + O^- &\rightarrow \text{CH}_3\text{CO}^+\text{CH}_2 + \text{OH}^- + e^- \quad (4) \\
\text{CH}_3\text{COCH}_3 \text{(gas)} + O^- &\rightarrow \text{CH}_3\text{C}^+\text{O} + \text{CH}_3\text{O}^- + e^- \quad (5) \\
\text{CH}_3\text{C}^+\text{O} &\rightarrow \text{C}^+\text{H}_3 + \text{CO} \quad (6) \\
\text{CO} + O^- &\rightarrow \text{CO}_2 + e^- \quad (7)
\end{align*}
\]

4. Conclusion
In this work, MQ-138 semiconductor sensor was successfully integrated into a system which is portable, fast and easy to operate. This system was applied for breath acetone detection in both diabetes and nondiabetes patients. It was revealed that the sensor readings to be linearly related to breath acetone indicated by the increasing of the sensor output voltage as the blood glucose values rising. Thus, the proposed system has a potential to be used for breath acetone detection as a new application of MQ-138 semiconductor sensor.

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