Development of MOX Gas Sensors Module for Indoor Air Contaminant Measurement

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Abstract. This paper presents the development of gas sensor module consisting of metal oxide (MOX) gas sensors for indoor air contaminant measurement. The first phase of the studies involves the design of PCBs board for six different metal oxide (MOX) gas sensors particularly CCS803, MiCS5524, GM-402B, GM-502B, GM-702B and MiCS6814. Next, the main board consisting of temperature, humidity and another two MOX gas sensors (i.e TGS2600 and TGS2602) was developed for the acquisition of the sensors. A partially closed chamber was designed and fabricated to fit the main board and allows inflow and outflow of gases. The responses of the gas sensors were measured in a closed room, with the air conditioner turned on and off periodically. The results show that all the MOX gas sensor used are affected by temperature and humidity of the environment. Therefore, the sensor response drift needs to be corrected in order to obtain reliable indoor air contaminant measurement.

1. Introduction

In this era, air contamination is one of the most concern issues that will lead to serious health diseases. According to the report from World Health Organization (WHO), 1.7 million of children died due to the exposure of contaminated environment [1]. The long-term exposure to the polluted environment will cause the life threatening disease. In 2016, Health Effect Institute stated that 6.1 million of people died from lung disease, lung cancer, heart attacks and strokes which caused by the air pollution [2]. Moreover, air pollution is not only limited to just outdoor, but also affects indoor environment, in which the impact is more serious to human.

The indoor air quality (IAQ) issue rise by many factors especially by the human daily activities without noticing it will lead to the pollution of indoor environment. The product that has been used such as air freshener, insect repellent, household cleaning reagent excessively causing the degradation of indoor air quality. Besides, human always neglects indoor air quality issues since it could hardly detected without the help of certain sensors. Some air pollution is odorless and could only be detected by the help of some type of sensing system. Therefore, researcher has been studying on the indoor air quality system that can help in monitoring indoor environment [3].

Volatile organic compound can be listed as one of the main pollutants that exist in atmosphere, which can cause chronic health disease and may also lead to the formation of ozone and mists. Volatile organic
compound can be found in many household items and it can easily vaporize at room temperature and pressure which will lower the level of indoor air quality[4]. For example, cleaning reagent that is used in daily activities is the major source of ethanol gas in indoors. It is important to perform indoor air quality monitoring to track on the quality of the air[5].

As technology nowadays has growth exponentially, there is numbers of affordable gas sensor available in market such as resistive sensors, electrochemical sensors, non-dispersive infrared (NDIR) detectors and photoionization detectors (PIDs) [6]. Among all of the gas sensors, resistive metal oxide gas sensor (MOX) has been widely used due to lower in price, smaller in size where offer a lightweight design, low consumption and long-life [7]. The high sensitivity to a large numbers of gases and have a quick responds time increase the market of this type of gas sensor. Due to the ability of the MOX sensor, it has been used in many applications of environmental monitoring [8]. The basic design of MOX sensor is a thin films of metal oxide deposited on a silicon substrate and reaction occur on the surface of the MOX sensors causing a variation of sensing element [9]. This will act as an electrical resistive transducer and the resistance is proportional to the number of molecules absorbed. The MOX gas sensor resistance value will fall when exposed to gas, this fall of resistance is non-linear with increasing gas concentration in the gas measurement [10].

In previous studies, researchers have been discussing on the limitations of MOX sensor, and shows that this type of sensors have limited sensitivity, high power consumption and temporal drift. Kamarudin et al. discussed on the effect of ambient temperature and relative humidity on the gas sensor response and gas distribution map [11]. On another study, he stated that the operating temperature of gas sensor’s sensitive layer should be kept between 200-500°C to improve the selectivity and respond rate of the gas sensor. Moreover, the humidity effect on the gas sensor response can be reduced when the temperature is maintained well above 100°C [12]. Therefore, the present study focuses on the development of the sensor’s board with chamber for monitoring volatile organic compound (VOC). The aim is to study the respond of different MOX gas sensors in normal indoor environment (i.e. with and without air conditioning) where temperature and humidity fluctuates.

2. Gas Sensor Circuit Development
This section presents the process of developing different MOX gas sensors circuits which include the sensor selection, PCB design and fabrication.

2.1 Selection of Gas Sensors
Most of the gas sensors are not suitable for this experiment due to their lack of volatile organic compounds (VOCs) detection and their concentration limits, where some others can fit such as metal oxide (MOX). There are several reasons why MOX gas sensors are the best selection for this study, which is relevant to (VOCs) and their detection ranges. Table 1 shows eight MOX sensors selected for this study and their features.

These types of sensors were chosen due to their ability to give the desired response to the set parameters; temperature, humidity and gases type, in a way to meet the scope limitation of this study. These gas sensors were proven to provide a reliable result and are widely used due to their stability and relatively high sensitivity compared to other models. According to the datasheet, all the sensors are able to detect VOCs and therefore is deemed suitable for the requirement. The detection range of the sensors is also low (i.e below 1000ppm) which is suitable for indoor air contaminant measurement application.
Table 1. Selecting a gas sensor for the PCB board

| Sensor type   | Target gases                  | Detection range       | Features                                                                 |
|---------------|-------------------------------|-----------------------|---------------------------------------------------------------------------|
| GM-502B [12]  | Carbon monoxide (CO)          | 1-1000ppm             | • Low power consumption.                                                  |
|               | Nitrogen dioxide (NO3)        | 10-500ppm             | • High sensitivity.                                                       |
|               | Ethanol (C2H5OH)              | 1-1000ppm             | • Fast response.                                                          |
|               | Hydrogen (H2)                 | >1000ppm              | • Simple drive circuit.                                                   |
|               | Methane (CH4)                 | >1000ppm              |                                                                           |
| GM-402B [14]  | Methane (CH4)                 | 1-1000ppm             | • Low power consumption.                                                  |
|               | Propane (C3H8)                | 1-5000ppm             | • High sensitivity.                                                       |
| MiCS5524 [15] | Carbon monoxide (CO)          | 1 – 1000ppm           | • Fast response.                                                          |
|               | Ethanol (C2H5OH)              | 10 – 500ppm           | • Simple drive circuit.                                                   |
|               | Hydrogen (H2)                 | 1 – 1000ppm           |                                                                           |
|               | Methane (CH4)                 | >1000ppm              |                                                                           |
| MiCS6814 [16] | Carbon monoxide (CO)          | 1 – 1000ppm           | • Smallest footprint for compact design.                                  |
|               | Ethanol (C2H5OH)              | 10 – 500ppm           | • Robust MEMS sensor for harsh environments.                              |
|               | Hydrogen (H2)                 | 1 – 1000ppm           | • High-volume manufacturing for low-cost applications.                    |
|               | Methane (CH4)                 | 1-500ppm              |                                                                           |
|               | Propane (C3H8)                | >1000ppm              |                                                                           |
| GM-702B [17]  | Methane (CH4)                 | 1-500ppm              | • Low power consumption.                                                  |
|               |                               |                       | • High sensitivity.                                                       |
|               |                               |                       | • Fast response and resume.                                               |
|               |                               |                       | • Simple drive circuit.                                                   |
| CCS803 [17]   | Ethanol (C2H5OH)              | 5 – 10ppm             | • low power consumption.                                                 |
|               |                               |                       | • High sensitivity to Ethanol.                                            |
| TGS2600 [19]  | Methane                       | 1-100ppm              | • Low power consumption.                                                  |
|               | Carbon                       |                       | • High sensitivity to gaseous air contaminants.                           |
|               | Butane                       |                       | • Long life and low cost.                                                |
|               | Ethanol                      |                       | • Uses simple electrical circuit.                                         |
|               | Hydrogen                     |                       | • Small size.                                                            |
| TGS2602 [20]  | Methane                       | 1-50ppm               | • High sensitivity to VOCs.                                               |
|               | Carbon                       |                       | • Low power consumption.                                                 |
|               | Ethanol                      |                       | • High sensitivity.                                                       |
|               | Hydrogen                     |                       | • contaminants Long life.                                                |
|               |                               |                       | • Use simple electrical circuit.                                          |
|               |                               |                       | • Small size.                                                            |
2.2. Gas Sensor’s Board Design

2.2.1 Schematic design and PCB layout design

Figure 1 and Figure 2 show schematic diagram and the PCBs layout of six PCB circuits for CCS803, MiCS5524, GM-402B, GM-502B, GM-702B and MiCS6814. The reason of designing individual board for each sensor is because in the future if any of the sensors mounted onto the board is damaged there will be a difficulty replacing it since it is applied to the board using surface-mount technology (SMT). Furthermore, if it was designed without modularity in mind, losing one sensor causes the whole board to be unusable. To avoid such case, it is preferable to build and develop separate boards for each gas sensor then connect them all into one main prototype. This procedure helps in different aspects in addition to the one mentioned earlier. Tests on each individual sensor can be performed to ensure its functionality and efficiency. In this case, if any of the sensors shows malfunction after the test then it can be replaced with relative ease. The arranging of the small PCB gas sensors on main board, after knowing all sensors are checked, is easier where all sensors are set in two lines near each other in order to ensure that they are exposed to the gas and each sensor gets to detect it simultaneously.

![Schematic circuit](image1)

**Figure 1.** Schematic circuit of several types of the gas sensor’s (a) CCS803 (PCBV1), (b) MiCS5524 (PCBV2), (c) GM-402B (PCBV3), (d) GM-502B (PCBV4), (e) GM-702B (PCBV5) and (f) MiCS6814 (PCBV6).
Figure 2. PCBs layout design of several types of the gas sensor’s (a) CCS803 (PCBV1), (b) MiCS5524 (PCBV2), (c) GM-402B (PCBV3), (d) GM-502B (PCBV4), (e) GM-702B (PCBV5) and (f) MiCS6814 (PCBV6).

2.2.2 Main PCB board design
This section describes the development of main PCB board that includes TGS2600, TGS2602 gas sensor, temperature sensor and humidity sensor. Figures 3 and 4 show the schematic diagram and PCB design for the main board respectively. To ensure that the flow of gas crosses smoothly on sensors’ sensitive part, the SMD gas sensors (refer Section 2.2.1), TGS2600 & TGS2602 sensors were arranged at similar height and close to each other to ensure they are induced with similar gas concentrations. Temperature and humidity sensors were added to enable other parameters related to the environment in proximity to the gas sensors to be captured/recorded. Multiple voltage regulators are used to provide the sensors with correct DC Voltages. The circuit is designed on a double-sided PCB. A double-sided PCB consists of two copper layers on both sides of the substrate layers. The double-sided PCB improves the component density used on the board and minimizes the circuit traces needed in a single sided PCB.

Figure 3. Complete main Schematic design of the gas sensors.
Figure 4. (a) top layer view (b) bottom layer view of the complete PCB board with sensors.

3. Closed Chamber design

Figure 5 shows a partially closed chamber that will be used to control the inflow and the outflow of the gas. It allows the measurement of low flow rates accurately since; the gas is less disturbed by the environment. Additionally, the use of a chamber will eliminate unwanted effects from the environment. Note that the chamber consists of air strips at the top cover that allows the exchange of the air in the chamber and the air outside the chamber. This design will ensure that the temperature will not rise beyond the desired temperature due to the built-in heater of the gas sensors.

Figure 5. A partially closed chamber was designed to allow inflow and outflow of gas in and out: (a) shows the placement of the PCB board inside the chamber, and (b) shows the external chamber

4. Experimental Results

This section describes the results of the two experiment conducted using the integrated gas sensors board. The gas sensor board was tested placed inside the chamber as well as without the chamber. The experiment was conducted in a closed room where the air conditioner was switched on and off periodically for every 2 to 3 hours. The NI USB-6211 was used to collect the data and displayed on LabVIEW front panel. Figure 6 shows temperature, humidity and gas sensors resistance with respect to time for both experiments.
Figure 6. The plots for temperature, humidity and gas sensors response (Rs) with respect to time where a) the experiment was conducted without chamber b) the experiment was conducted using the chamber.
Referring to Figure 6, the temperature and humidity for both experiments fluctuate according to the air-conditioning. When turned on, the temperature and humidity drops and opposite behavior is observed while it is turned off. The temperature and humidity for both approaches, with or without the chamber shows similar levels since it has airstrips (refer Figure 5) s. All sensors are affected by temperature and humidity where the combined increase in temperature and humidity generally cause the sensor response to significantly decrease (though there is no gas release) and vice versa. It is important to note that the plots obtained using the chamber generally contains less noise than without the chamber. Moreover, the GM-502B, GM-702B, TGS2600 and TGS2602 gas sensors are seen to have lesser noise for both experiments conducted with and without chamber. Overall, the outcomes suggest that the correction to temperature and humidity drift is required to improve the reliability of the metal-oxide gas sensor response.

5. Conclusions
In this paper, the integrated gas sensor module was developed for indoor air contaminant monitoring applications. The metal-oxide (MOX) gas sensing technology has been reported as the most widely used technology in monitoring. These sensors are however cross-sensitive to the temperature and humidity of the environment. Therefore, to verify and study the significance of the cross-sensitivity problem, PCB boards containing different MOX gas sensors have been developed together with partially closed chamber. The experiment on the system was conducted in closed room with and without chamber under different air-conditioning control. It was found that all the MOX gas sensors are significantly affected by temperature and humidity of the environment, where the responses are more stable (i.e less noise) when the board is placed inside the chamber. Therefore, it is recommended that these drifts are corrected in order to obtain reliable indoor air contaminant measurement.

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