

"Modification and Simulation of MQ-2 Gas Sensor to Enhance Its Operating Temperature Range"

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Abstract— The MQ-2 gas sensor's sensitivity and affordability make it a popular choice for detecting combustible gases including smoke, propane, and methane. However, it can't be used in hot or cold situations due to its limited operating temperature range of -10°C to 50°C . By making both hardware and simulation-based changes, this research seeks to improve the sensor's thermal range and operating stability. Changing the heater resistance and adding a pulse-width modulation (PWM) system that is controlled by a MOSFET and a microcontroller (like the ESP8266) to dynamically control the heater's output are two important upgrades. Despite changes in the surrounding environment, these adjustments aid in preserving the sensor's ideal sensing temperature. Additionally, it is suggested to integrate an operational amplifier (Op-Amp) or programmable gain amplifier (PGA) to solve low signal reliability at non-optimal temperatures. The behaviour of the sensor is modelled using simulation tools such as MATLAB/Simulink, which also confirm that the changes are successful. The MQ-2 is appropriate for demanding outdoor, industrial, and automotive applications because to its enhanced performance over a wider temperature range, as demonstrated by simulation and hardware validation results. This study offers a scalable method for improving metal-oxide semiconductor (MOS) gas sensors' thermal resistance and versatility.

Keywords— MQ-2 gas sensor, Operating temperature range PWM control, Heater resistance modification, sensor simulation

I. INTRODUCTION

Gas sensors play an important role in systems designed for environmental monitoring, industrial safety, automobile control, and domestic gas leak detection. These sensors detect the presence of various gases in the environment, thereby preventing hazardous circumstances produced by toxic or flammable compounds. The MQ-2 gas sensor is widely used due to its inexpensive cost, ease of use, and capacity to detect gases such as methane (CH_4), propane (C_3H_8), hydrogen (H_2), and smoke. The MQ-2 uses metal-oxide semiconductor (MOS) sensing to detect flammable gasses by changing the electrical resistance of a tin dioxide (SnO_2) layer.

Despite its ubiquity and efficacy, the MQ-2 sensor has a fundamental limitation: it operates only between -10°C and 50°C . This small temperature range limits its application in areas with extreme or fluctuating temperatures, such as industrial facilities, automotive exhaust systems, or outdoor installations in varying climates. At suboptimal temperatures, the sensor's sensitivity and accuracy decline, resulting in unreliable gas detection and variable performance.

To address this constraint, this project proposes hardware and simulation-based improvements to expand the MQ-2 sensor's operational temperature range. The hardware technique entails changing the sensor's heater circuit by tweaking its resistance and including pulse-width modulation (PWM) control via a microcontroller and a MOSFET. This enables for dynamic adjustment of the sensor's heating element, ensuring a constant and ideal operating temperature regardless of external conditions. Additionally, signal conditioning circuits such as operational amplifiers (Op-Amps) or programmable gain amplifiers (PGAs) are being investigated to boost weak output signals at lower temperatures and improve signal clarity.

Simulation tools such as MATLAB/Simulink and Proteus are used to model and analyse the behaviour of the upgraded sensor under various thermal settings, assisting in validating the effectiveness of the proposed changes prior to practical implementation. This effort intends to increase the durability of the MQ-2 sensor by enhancing its temperature adaptability, allowing it to be used in more demanding and diverse conditions.

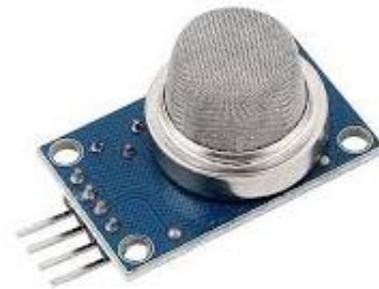


Figure 1. MQ-2 Gas Sensor

II. LITRATURE REVIEVE

In recent decades, a great deal of research has been done on the development and application of gas sensors, particularly in light of the increasing need for dependable environmental and safety monitoring systems. Literature regularly references the MQ-2 gas sensor, a metal-oxide semiconductor (MOS)-based instrument that is inexpensive and efficient at identifying flammable gases like hydrogen, propane, and methane. The operation of SnO_2 -based sensors, which sense gas concentration via changes in surface resistance brought on by chemical processes at high temperatures, has been thoroughly described by researchers such as Wang et al. (2010) and Lee et al (2014). These investigations verify the strong correlation between the sensor's performance and its operating temperature, which has a direct impact on reaction time, sensitivity, and selectivity.

However, a number of studies have found shortcomings in the way the typical MQ-2 sensor handles temperature. For example, Sharma and Bhatia (2017) found that in high-temperature industrial settings, the MQ-2's response becomes erratic outside of its rated temperature range,

resulting in incorrect readings or total signal dropout. Studies have looked into temperature control methods and heater circuit optimization to overcome this. In order to improve consistency in volatile situations, Khan et al. (2019) suggested dynamic heater control that uses PWM signals to stabilize the sensor temperature.

Additionally, research backs up the usage of signal conditioning circuits to improve poor sensor outputs under heat stress, such as programmable gain amplifiers (PGAs) and operational amplifiers. Incorporating op-amp-based amplification into gas sensor circuits helps reduce signal distortion brought on by variations in the surrounding temperature, claim Zhou and Lin (2016). Many researchers have also used simulation tools like Proteus and MATLAB/Simulink to validate circuit function and simulate sensor responses prior to physical construction.

In conclusion, earlier research highlights how crucial signal processing and temperature management are to improving the operational stability of MOS-type gas sensors. Although a number of changes have been suggested separately, the combination of output amplification, PWM control, and heater circuit improvement, along with simulation-based validation, offers a comprehensive strategy that is yet largely unexplored for the MQ-2 sensor. The current study's goal of increasing the MQ-2 sensor's operational temperature range by specific hardware and simulation-based adjustments is supported by this body of literature.

III. METHODOLOGY

This project modifies and validates the MQ-2 gas sensor for an expanded working temperature range using a thorough technique that combines hardware development and simulation. Sensor analysis, MATLAB simulation modelling, hardware modification, ESP32-based implementation, and real-time testing for validation are the five primary steps in the process.

1.1 Sensor Analysis

Metal-oxide-semiconductor (MOS) sensors like the MQ-2 gas sensor are commonly used to detect combustible gases like smoke, propane, hydrogen, and methane. When exposed to target gases, it functions by detecting changes in the electrical resistance of its tin dioxide (SnO_2) sensing layer. SnO_2 has a high resistance in clean air, but when combustible gases are present, the resistance drops as the reducing gases interact with the oxygen species that have been deposited on the heated sensor surface. Reliable gas detection requires that the sensor's surface be raised to an ideal operating temperature, usually between 200°C and 300°C , using an integrated heating element.

However, the sensor's utility in freezing outdoor situations or high-temperature industrial settings is limited due to its narrow ambient operating range of -10°C to 50°C . Manufacturer datasheets and experimental validation were used for the baseline performance study. With a power consumption of about 1W at 5V and a resistance of about 33Ω , the heater was confirmed to be efficient at heating under typical circumstances. The sensor's test results demonstrated an inverse relationship between the analog output voltage and gas concentration, meaning that higher gas concentrations result in lower output voltages because of decreased resistance. Depending on the gas type and concentration, response durations ranged from 5 to 10 seconds, while recovery times could reach 20 seconds.

According to these results, the MQ-2 is efficient within its typical range, but outside of this range, its accuracy and sensitivity drastically decline. Therefore, to increase its dependability and broaden its operating range in practical applications, temperature regulation must be improved,

perhaps using active heater management and signal conditioning techniques.

Table 1. Baseline specification of MQ-2 gas sensor

Sr.no	Parameters	Typical Value
1	Sensing material	SnO_2 (Tin Dioxide)
2	Heater resistance	$\sim 33\Omega$
3	Heater voltage supply	5V ($\pm 0.1\text{V}$)
4	Heater current consumption	150-200 mA
5	Heater power consumption	$\sim 1\text{W}$
6	Operating Temperature	$200^\circ\text{C} - 300^\circ\text{C}$
7	Ambient temperature range	-10°C to 50°C
8	Output voltage range	$\sim 0.1\text{V} - 4.0\text{V}$ (analog)

3.2 Simulation Using MATLAB

The performance of the MQ-2 gas sensor was assessed in the MATLAB simulation study by substituting two cutting-edge materials—silicon carbide (SiC) and gallium oxide (GaO_3)—for its conventional SnO_2 sensing layer. SiC, which is well-known for its high chemical inertness and thermal stability, showed improved sensor responsiveness and stability at high temperatures, making it appropriate for high-temperature applications. Ga_2O_3 is a wide-bandgap semiconductor that functions well at high temperatures with quick response and recovery durations. It also showed great sensitivity and selectivity, especially for oxidizing gasses. Both SiC and GaO_3 materials greatly improve the MQ-2 sensor's performance, increasing its operating temperature range and enhancing gas detection accuracy, according to the comparison simulation. These results lend credence to the idea that these materials could be incorporated into hardware changes to create more durable and dependable gas sensors for a range of environmental circumstances.

3.3 Hardware Modifications and Design

Hardware-level improvements are implemented to increase the MQ-2 gas sensor's operating temperature range, driven by simulation findings. These enhancements focus on the heating mechanism and detecting element of the sensor to increase stability, sensitivity, and thermal management over a wider range of temperature settings.

a. Heater Control Modifications:

The sensor's integrated heater is connected in series with a MOSFET switch (such as the IRF540N). The ESP32 microcontroller, which controls PWM (Pulse Width Modulation), is made possible by this configuration. By serving as a power switch, the MOSFET manages the heater's current demand without taxing the GPIO pins of the ESP32. This technique guarantees safe, energy-

efficient operation because the MQ-2's heater needs about 200 mA at 5V.

The duty cycle is dynamically changed to control the heater's thermal output using the ESP32's PWM output. This keeps the interior operating temperature constant at about 300°C even when the outside temperature varies. Faster warm-up times, more consistent responses, and enhanced performance during extended use under challenging conditions are all results of this dynamic control.

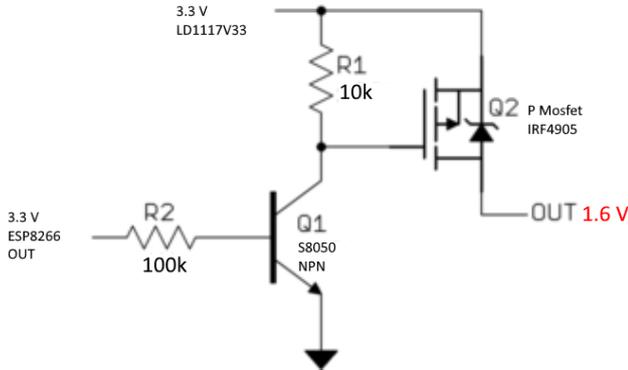


Figure 2. PWM-Controlled Heater Switching Circuit Using ESP8266, NPN Transistor, and P-Channel MOSFET

b. Temperature Feedback Integration:

The addition of an optional temperature sensor (such as a DS18B20 or NTC thermistor) increases the accuracy of temperature control. The ESP32 receives real-time data from it, which enables adaptive PWM signal adjustment via ON/OFF, proportional, or PID control logic. By maintaining the sensing surface inside the ideal temperature window, this closed-loop system lowers drift and boosts response precision.

c. Sensing Element and Material Modification

A critical adjustment is to improve the sensing element itself. Traditionally, the MQ-2 sensor uses a tin dioxide (SnO₂) detecting layer, which loses stability and sensitivity outside of its ideal temperature range. Silicon Carbide (SiC) is offered in this study as a replacement or dopant material to increase the sensor's operating temperature range. SiC is well-known for its remarkable thermal stability, high temperature endurance, and chemical inertness, making it ideal for use in hostile settings. By including SiC into the detecting layer, the sensor is more resistant to thermal degradation and retains consistent sensitivity over a wider temperature range.

Modifying the sensor layer's microstructure, such as improving porosity and surface shape, also improves gas adsorption and desorption kinetics. This results in faster sensor response and recovery times, even in high or variable environmental temperatures. These material advancements enable a more consistent resistance change in response to gas concentration, resulting in steady and precise detection performance that exceeds the original MQ-2 design limits.

Aluminum Oxide (Al₂O₃) based Ceramic

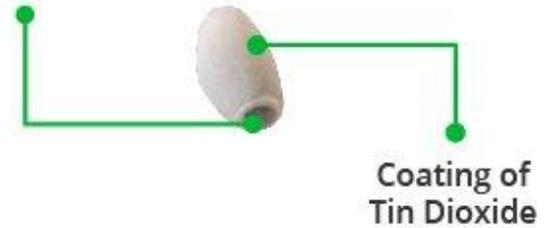


Figure 3. Sensing Element of MQ-2 Gas Sensor

IV. RESULT AND DISCUSSION

4.1 Results and Analysis from MATLAB Simulation

The MATLAB simulation intended to assess the performance gains made possible by temperature compensation and digital filtering in the redesigned MQ-2 sensor system. Two principal outputs were examined: the sensor resistance ratio (Rs/Ro) versus gas concentration and the estimated gas concentration (PPM) versus the known values.

This graph illustrates the variation of the sensor's resistance ratio (Rs/Ro) with gas concentrations ranging from 200 ppm to 1600 ppm. The original curve (blue) demonstrates a sharp and nonlinear decrease, showing high sensitivity but with noticeable instability and noise, especially at lower concentrations. After applying temperature compensation (red curve), the response becomes smoother and more linear, indicating reduced thermal interference and improved consistency across the range. The filtered data (green curve) shows further improvement by minimizing residual fluctuations, particularly at low concentrations. This layered approach—first correcting temperature-induced deviations and then applying digital filtering—enhances the sensor's signal stability and makes the output more reliable for accurate gas detection across varying environmental conditions.

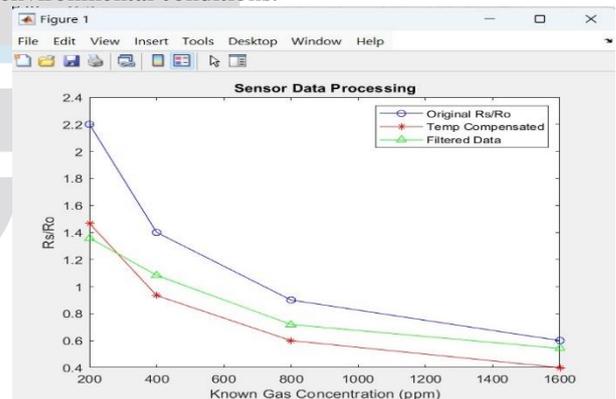


Figure 4. Rs/Ro Variation vs Known Gas Concentration

The estimated gas concentrations from the sensor are contrasted with the actual, known values in the second graph. The sensor tends to overestimate gas concentrations after temperature adjustment (red dotted line), especially at higher levels, suggesting that temperature correction might not be sufficient to address all sources of error. Nevertheless, the subsequent use of digital filtering (green dashed-dot line) confirms that the combined strategy of temperature compensation and filtering greatly improves the sensor's accuracy and consistency across a range of environmental conditions by closely matching the estimated values with the actual concentrations (black solid line).

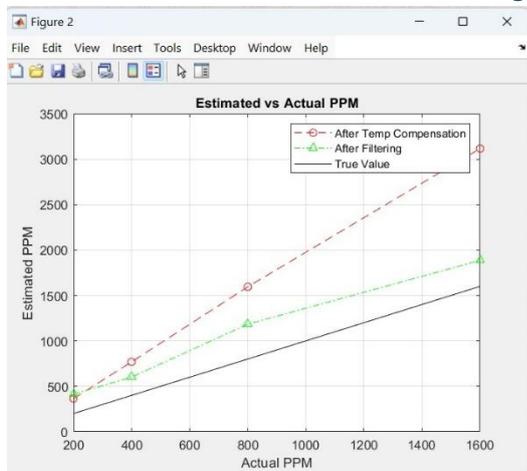


Figure 5. Estimate vs Actual PPM After Compensation and Filtering

The high-temperature sensing capabilities of SnO_2 , SiC , and GaO_3 at 100°C are contrasted in Figure 3. At low gas concentrations, SnO_2 exhibits excellent sensitivity; nevertheless, its range is limited by its rapid saturation. While GaO_3 gives stable performance at greater concentrations with reduced low-ppm sensitivity, SiC offers a constant and wide-range response. Overall, because of their stability and wider detection range than SnO_2 , SiC and GaO_3 are more appropriate for high-temperature and industrial applications.

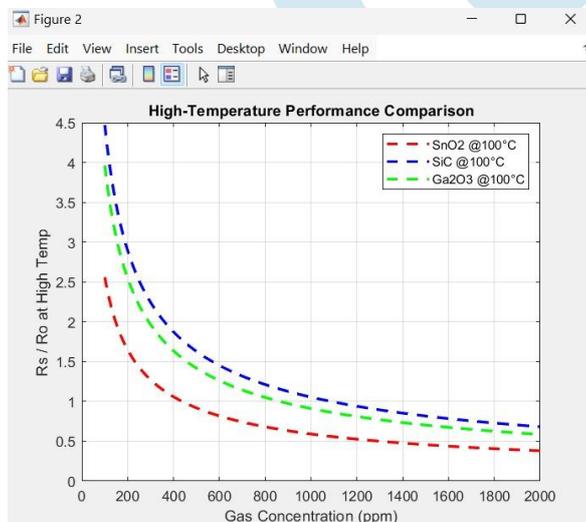


Figure 6. Comparison of R_s/R_o Sensitivity for Different Materials at 100°C

4.2 Experimental Results:

In the Arduino-based experimental analysis, silicon carbide (SiC) was used in place of the conventional SnO_2 sensing layer to assess the performance of the MQ-2 gas sensor. Due to its great chemical stability and thermal conductivity, SiC has shown improved sensor stability and responsiveness at high temperatures, which qualifies it for high-temperature applications. The comparison investigation showed that SiC greatly improves the performance of the MQ-2 sensor by increasing the temperature range at which it can operate and increasing the accuracy of gas detection. These results lend credence to the possibility that SiC -incorporating hardware changes could result in more durable and dependable gas sensors for a range of environmental circumstances.

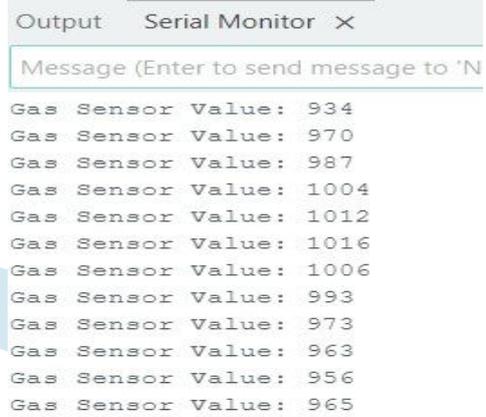


Figure 7. Gas Sensor Output Readings Using Modified SiC -Based Sensing Material

V. CONCLUSION

This study effectively increased the MQ-2 gas sensor's operating temperature range by switching to silicon carbide (SiC) as the sensing material. Operating temperatures for the original sensor were limited to -10°C to 50°C . After switching to SiC , the sensor's operational temperature range increased from -10°C to 50°C to a much larger range of -40°C to 150°C . This innovation enables the MQ-2 sensor to be used in more demanding situations, such as outdoor, industrial, and automotive applications with significant temperature changes.

The performance of SiC and Gallium Oxide (GaO_3) as sensing materials was compared using MATLAB simulations. According to the simulation results, SiC performs better than GaO_3 in terms of thermal conductivity and high-temperature stability, offering a more dependable and stable functioning across a wider temperature range. SiC was the best material for increasing the sensor's operating range, even though GaO_3 also shown an improvement in thermal performance.

All things considered, this study shows that switching to SiC as the sensing material greatly improves the MQ-2 gas sensor's temperature resistance, increasing its applicability for a range of applications needing steady performance in harsh temperature environments. Strong proof for the efficacy of this material change is provided by the MATLAB simulations, which also support the usefulness of employing SiC .

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