An Auto Calibrated Digital Interfacing Circuit Design to Monitor the Effect of Ambient Temperature Variation for Gas Sensor Applications

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Abstract: A simple and assimilated architecture is introduced to measure the gas concentration with a nanocrystalline metal oxide MEMS based gas sensor. The temperature of the sensor is stabilized by controlling the temperature of the microheater. ADCs and potential divider circuits are used to measure the heater temperatures by sampling the heaters resistance. PIC16F877A microcontroller is used here to adjust the output of DACs in order to apply the proper steering voltage to the microheater. The emphasis is given in the simplicity of the design and on the use of different simple methods. Also, a sole microcontroller is used to drive and control the microheater temperature, to operate independently from the variation of the environmental parameters, particularly ambient temperature. An easy compensation technique is developed to nullify the effect of ambient temperature deviation to have a fixed output voltage at fixed temperature of the microheater.

Keywords: Gas sensor; MEMS; microheter; microcontroller.

1 INTRODUCTION

The requirement of gas sensors is now everywhere including automation industries, domestic appliances, services, space exploration, biomedical application, defense equipment and so on. With the advancement of microfabrication technology and soft computing technique, sensors [1] have helped to accomplish precision and control of a system. Due to the higher surface to volume ratio nanocrystalline thin film based gas sensor has shown a remarkable performance in terms of higher sensitivity. This in turn lowers the operating temperature of the device as more surface areas are exposed to interact with the gases. Semiconducting metal oxide layer detect various gases by changing either its electrical conductivity or resistivity as reported by various researchers [1-3]. Among various metal oxides, ZnO is one of the promising materials [4]. The deposition techniques of ZnO those were reported, generally has higher annealing temperature (400–500°C) which in turn generates excessive thermal stress in the [5] membrane, reducing the life time of the device. To avoid this problem, a low temperature, low cost chemical

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deposition technique already been reported by Roy et.al. [4].

Low power consumption is an essential prerequisite for a sensor system with an adequate battery lifetime. Conventional metal oxide gas sensors, suffer from higher operating temperature (>=300°C) leading to high power consumption (>1W) [6]. In recent years, the application of Micro Electro Mechanical Systems (MEMS) based metal-oxide gas sensors have shown remarkably improved performance compared to the conventional one due to their low power consumption, miniaturization, higher sensitivity and faster response [2]. As the thermal conductivity of silicon is very high (150W/m-K), bulk micromachined devices provide extremely low thermal mass by eliminating bulk silicon counterparts and thus power consumption of the device is reduced. Another important aspect is that bulk micromachining employs wet etching technique which offers easier and quicker fabrication of membrane at laboratory level; MEMS technology recommends batch processing technique, thereby reducing cost of the device [7].

In this paper, a low cost, high resistivity (nickel alloy) microheater element is used to heat up the sensing layer (ZnO) within the range 100-200°C [4]. Microheater is used to keep the gas sensor at a constant temperature as well as to maintain the temperature uniformity of the device. This constant temperature is required to make a perfect gas sensor as at this temperature maximum reaction occurs. But there are so many unavoidable circumstances due to which it is difficult to maintain a constant heater temperature. One of the major reasons is ambient temperature variations. So there must be a compensation circuit which can nullify the effect of temperature fluctuations for proper functioning of the gas sensor.

A Semiconducting metal oxide gas sensor consists of an active layer (ZnO), a microheater made by Nickel (Ni) alloy, and electrodes, as shown in Fig. 1.

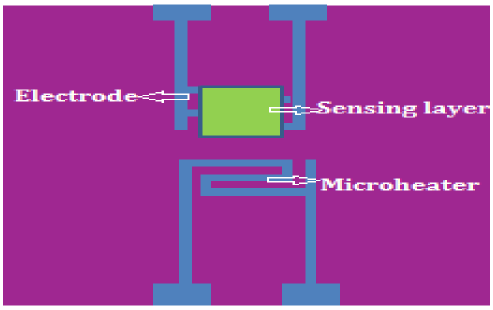

Fig. 1. Different parts of gas sensor.

Microheater resistance and consequently temperature changes by applying different voltages at its input.

It is well known that metal oxide gas sensor gives high accuracy and also high speed of response. Therefore for proper synchronization a high speed and high accuracy interface circuits should be used [1, 9] to drive the microheater rapidly to attain its target temperature enabling a fast self-calibration circuit compensating the effect of the ambient temperature variation.

There are several ways to find the solution such as the PWM technique [1], negative temperature coefficient (NTC) thermistor [10], resistance to frequency conversion, and resistance value controlled oscillator (RCO) [11] to compensate the effect. Mostly those are complicated. However, our design shows simultaneously a simple and automated circuitry to drive and control the microheater as well as compensating the ambient temperature effect.

2 DRIVING AND CONTROLLING THE MICRO-HEATER TEMPERATURE

The block diagram for measuring the target gas, driving and controlling the microheater temperature is given in Fig. 2. The microheater control block consists of marketable components which are listed below.

Microcontroller: The PIC16F877A microcontroller is used to drive and control the microheater as well as compensating the ambient temperature effect. PIC 16F877A microcontroller has been chosen because of its low price, wide range of application, high quality and ease of availability.

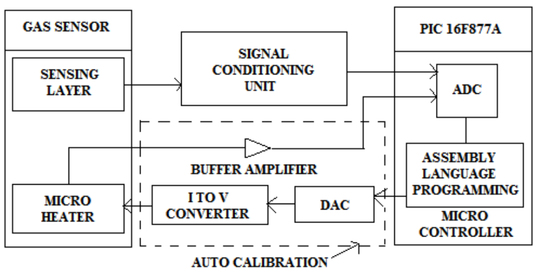

Fig. 2. Schematic of interface circuit designed for gas sensor.

DAC: The driving voltage is solely responsible to show the temperature of the microheater. A Digital to Analogue Convertor (DAC-0808) is used to provide the required voltage to the microheater based on the input from the microcontroller. The DAC was programmed by the microcontroller in order to apply the appropriate voltage to the microheater in a calibration procedure. The DAC

0808 is a monolithic 8-bit high-speed current converter, typical settling times of 150 ns. The total current obtained from the I_{out} pin, is a function of the binary numbers (D0-D7), input pins of 0808 and the reference current I_{ref}.

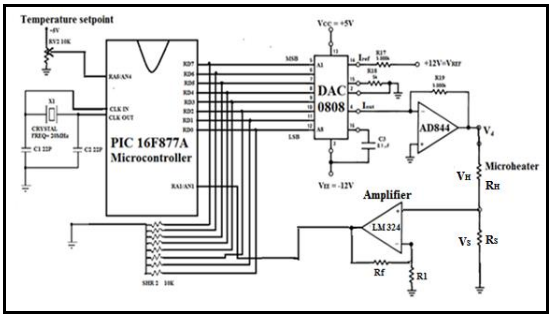

Fig. 3. Microheater tempetature control circuit.

Current to voltage converter: The I_{out} current output from DAC is isolated by connecting it to an op-amp such as the AD844with a feedback resistor R19=5k in Fig. 3. The AD844 works well as the active element in an operational current-to-voltage converter. This component is used to provide the constant driving voltage.

Buffer amplifier: The voltage drop on R_s is amplified using a buffer amplifier connected to 10 bit ADC, where a voltage V_s proportional to the current flow through the microheater.

ADC: The microcontroller keeps the track variation in the microheater resistance R_H through the ADC. The voltage drop over the microheater resistance R_H is sampled and given at the input of ADC. The ADC is inherent in the PIC 16F877A microcontroller which has a resolution of 10-bits analogue to digital converter.

Fig. 4 shows the picture of gas measurement set up used here.

The ambient temperature of the gas measurement

Fig. 4. Gas measurement set up.

setup was measured by a thermometer. The microheater resistance (R_H) and the microheater temperature (T_H) will increase by applying a higher voltage V_H to the microheater, obtained from the DAC and programmed by the microcontroller shown in Fig. 5 and the change in heater resistance shown Fig. 6.

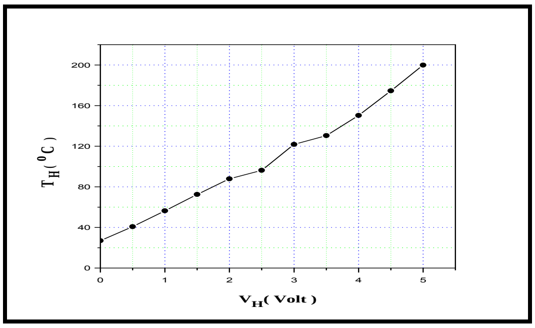

Fig. 5. Microheater temperature (TH) as a function of microheater voltage (VH) at 27˚C ambient temperature.

This voltage (V_H) is the real signal applied to the micro heater, and the temperature (T_H) is the actual quantity to be become stable.

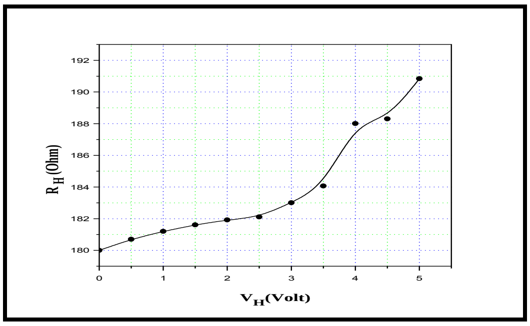

Fig. 6. Microheater resistance (RH) as a function of microheater voltage (VH) at 27˚C ambient temperature.

In Fig. 6 the relation between microheater resistance R_H and microheater voltage V_H and in Fig. 7 the relation between the microheater resistances R_H and the microheater temperature T_H are shown.

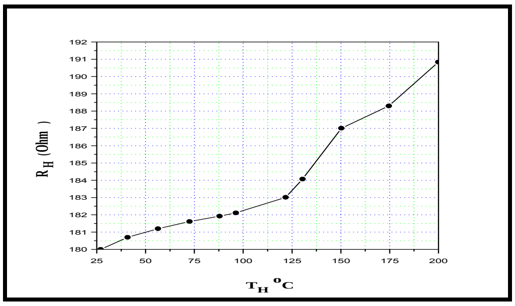

Fig. 7. Microheater resistance (RH) as a function of microheater temperature (TH) at 27◦C ambient temperature.

In these two curves, the fluctuations are more that means the error is larger, but still realistic and can be considered. The probable cause for these errors may be due to the nonlinear behavior of individual components which may not be the ideal case. In spite of the fact, almost linear trend in the relationships between V_H, T_H, and R_H are observed in Figs. 5-7. This makes it suitable for the practical use.

3 COMPENSATING THE EFFECT OF AMBIENT TEMPERATURE

Any change in the ambient temperature directly affects the temperature of the microheater and also the performance of the device. The effect of the ambient temperature on the microheater resistance is given in Fig. 8.

In this figure the voltage of the microheater V_H is kept constant, but the ambient temperature is set to 27˚C, 35.46˚C, 50.61˚C and 70.33˚C. Microheater resistance R_H increases when the ambient temperature increases as shown which is totally unwanted.

The relation between heater resistance R_H and ambient temperature is given by

$$R_H = R_{H0} (1 + \alpha (T - T_0)) \qquad (1)$$

Where α is the temperature coefficient of resistance, T_0 is the reference ambient temperature (27˚C), and T is the measured temperature (˚C), R_{H0}= microheater resistance at $T_{ambient}$.

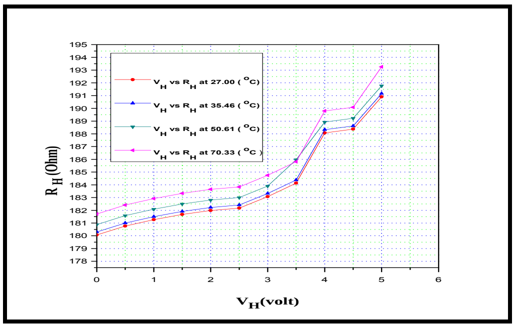

Fig. 8. Effect of ambient temperature on microheater resistance RH: curves at 27˚C, 35.46˚C, 50.61˚C and 70.33˚C.

This variation can be overcome by using the circuitry as shown in Fig. 9. A resistor R_s << R_H is connected in series with the microheater to monitor the current I_h flowing through the microheater. The voltage drop on Rs is amplified using a buffer amplifier connected to 10 bit ADC, where a voltage V_s proportional to the current flow through the microheater.

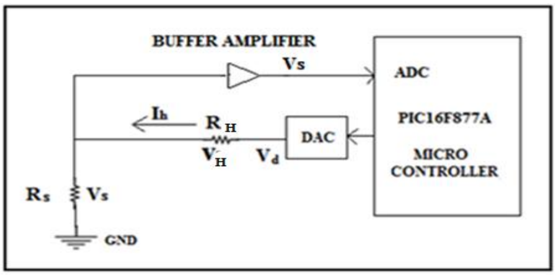

Fig. 9. Schematic circuit for compensating the ambient temperature.

Variation in microheater resistance R_H due to the variation of the ambient temperature, in turn change the current I_h flowing through the microheater. This current is also passed through the standard resistance R_s which results in a change of the voltage V_s across R_s. The effect of ambient temperature change on the voltage across the standard resistance V_s is shown in Table I. The driving voltage of the heater V_d is kept constant and the ambient temperature (T_a) is set to 27˚C, 35.46˚C, 50.61˚C and 70.33˚C gradually.

From table I, it is clear that V_s decreases with the increase in ambient temperature. Microheater resistance R_H can be found from equation 2 given below:

$$R_H = (V_d - V_s) / I_h \qquad (2)$$

Table 1. Effect of ambient temperature on V_s at 27 ˚C, 35.46 ˚C, 55.61˚C and 70.33 ˚C

V_d(V)	V_S (mV)			
	T_a=27 (˚C)	T_a=35.46 (˚C)	T_a=50.61 (˚C)	T_a=70.33 (˚C)
0.63	402.504	402.393	401.967	400.953
1.30	803.244	803.022	802.173	800.145
1.90	1171.866	1171.542	1170.3	1167.345
2.60	1601.433	1600.992	1599.297	1595.25
3.20	1969.359	1968.819	1966.731	1961.757
3.80	2329.464	2328.822	2326.353	2320.461
4.40	2684.901	2683.26	2681.31	2674.515
5.00	2999.871	2999.043	2995.842	2988.219
5.70	3415.62	3414.69	3411.03	3402.36
6.30	3734.85	3733.8	3729.81	3720.3

It is obvious that to keep the R_H I_H constant driving voltage (V_d) to the microheater must be decreased accordingly to keep the microheater temperature constant.

This is done by sampling V_s to the ADC and instructing the microcontroller, to provide the correct and compensating driving voltage to the microheater through the reprogramming of DAC.

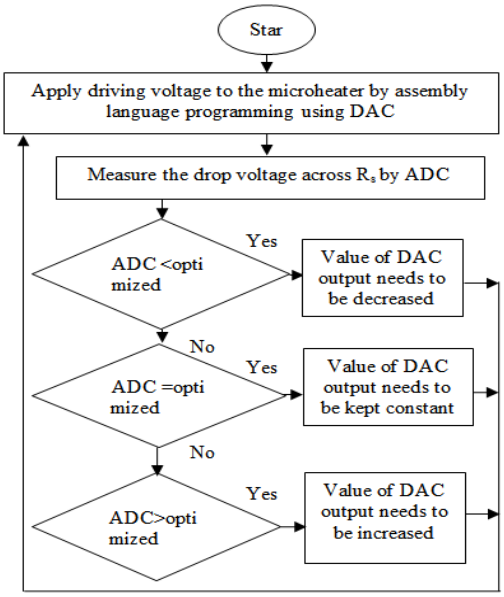

Fig. 10. Flow chart showing compensation technique.

The flow Chart describing the above phenomenon is shown in Fig.10. It is evident that, a driving voltage has been supplied through the DAC to drive the microheater. The resulting voltage drop across R_s is sampled by the ADC and is compared to the optimized value. The microheater temperature kept constant by compensating the effect of ambient temperature change on the microheater.

4 CONCLUSION

Designing of an auto-calibrated interface circuit for a metal oxide MEMS based gas sensor has been presented. The main objective is to drive the microheater and to keep the heater temperature constant by compensating the effect of ambient temperature change. The design uses available commercial components with automaticity and simplicity.

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