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A Low Power Cantilever-Based Metal Oxide Semiconductor Gas Sensor for Green House Applications

N.Siddaiah[1],V.V.Praveen[2],P.KavyaSri[3],Y.GaneshBabu[4],G.Venkata Ganesh[5]
[1]Associate Professor, Department of Electronics and Communication Engineering,Koneru Lakshmaiah Education Foundation, vaddeswaram-522302, AP, India
[2,3,4]UG Students, Department of Electronics and Communication Engineering ,Koneru Lakshmaiah Education Foundation, vaddeswaram-522302,AP,India
[5]AssistantProfessor, Department of Electronics and Communication Engineering, Koneru Lakshmaiah Education Foundation,vaddeswaram-522302,AP,India

ABSTRACT

This paper discuss about the detection of gas using MEMS. The main purpose is to design a metal oxide semiconductor based gas sensor with different types of cantilevers We simulated a design with cylindrical, rectangular and we compare the results. By gas detection from the circuit, there has been wide measurement range and high resolution to fulfill an gas sensor. A width of 10µ cantilever on which a sensing material is used and placed on the platinum micro heater without coil, which will provide less consumption of power and better heating with in less time. The circuit has been designed with a metal-oxide semiconductor technology to reduce the power consumption and suggest the best physical architecture

Key words: Cantilever,CO2, Gas Sensor, Metal oxide

1. INTRODUCTION

Gas sensors play a vital role in most of the applications in environment, home appliances, industrial field and aerospace field. The sensors and the way of detection are most important for identifying the gas which we are using in the circuit[1]. The gas detection sensors need more high sensitivity. The main principle of detection of gases through MOS gas sensors is by using voltage divider method [2-5]. These gas sensors have a crucial role in some of the fields like food, oil refineries, and household gas and for water treatment purposes.

One of the crucial part for this application level is low power, which reduces the power and size. Optimizing the structure will decrease the power dissipation for the developing sensing materials which are operating at lower temperature. The power consumption depends on the structure chosen [6]. The range of power consumed was 50-80 mw .This was obtained for the gas sensors which are based on micro heaters [7-9]. And the sensors with a membrane placed over a cantilever. By applying the voltage, sensor can reach up to certain heating temperature. Range of power consumed for the sensors which are supported by Cantilever was about 10-30 mw [10]. By using micro heater the static power consumption is very low. Further on application of a pulse modulated signal it can greatly reduce the static power dissipation.

The widely-used detection mechanism of MEMS gas sensors was mostly dependent on the voltage divider [11].The dimensions of the sensor and the quantity of sensing materials determine the limits of temperature and heating time, because of the relation between thermal and active regions[12-16].The sensor shows good characteristics at CO2 due to a single cantilever. The working principle of the metal oxide based gas sensor is that it changes the resistance of the Sensing film by adsorption of the gas molecules over the surface of the semiconductor. So the concentration of the gas can be detected by measuring up the sensor.

A sensor of MOS based which is provided with single micro cantilever because the sensor has ultralow power consumption and heating temperature. As the wheat stone bridge and current source method are very convenient to apply[17] and detect the gas sensors. By gas absorbed the resistance will change greatly.[18-20] So that gas concentration can be measured due to change in the resistance of the material.

The main application of this sensor are they help in monitoring of air quality and fermentation process in the preparation of wine and bread i.e,In food processing industries[21-26] .They are also used in agricultural related applications for the elimination of pests[25-30].

The first chapter covers explaining the physical structure of the gas sensor system and the second section discusses the mathematical modeling associated with the phase of detection. The last section discusses the results of the model.

2. PHYSICAL ARCHITECTURE AND DIMENSIONS OF GAS SENSOR:

A MOS based gas sensor is designed with SnO2 as sensitive material and a crystalline silicon(si) as base i.e., substrate, Generally a sensor consists of a supporting layer for insulation in this sensor sio2 will serve as supporting layer, A micro-heater for providing a temperature which is suitable to work or to provide necessary heat for the reaction to be occur over the sensor by application of voltage here heater made up of platinum serve the purpose ,electrodes which are used to detect the change in voltage. The isolation layer which provides isolation between the electrodes and micro heater electrodes. . A sensing film with the resistance of SnO_2 is connected between pt electrodes. The sensor comprises four pads, two for detecting the response signal a nd the other two for power supply for heating.

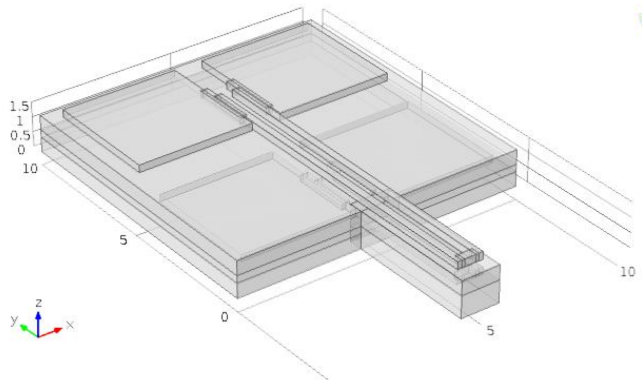

Figure 1: Gas sensor with Rectangular cantilever

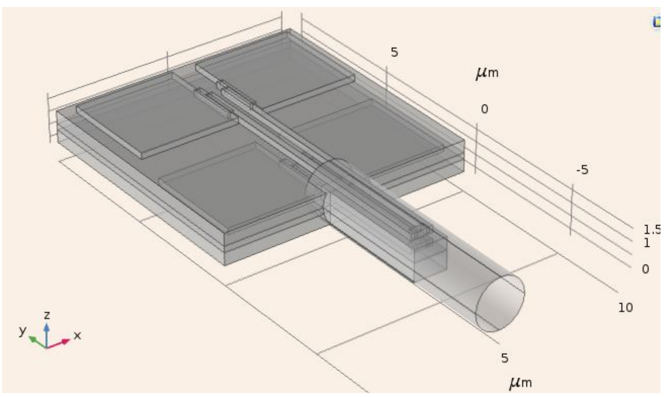

Figure 2: Gas sensor with cylindrical cantilever

Table 1: Dimensions of the Elements Used

S.No	Structural Element	Value
1.	Substrate	20µm
2.	Insulation Layer	10µm
3.	Electrodes	4µm
4.	Cantilever	100µm

3. MATHEMATICAL MODELING OF GAS SENSOR

MEMS Micro-heaters are capable of generating high temperature even in presence of low power and provide a fast response. Micro-heaters are made up of thin film or wire of heater coil which may be suspended inside the silicon layer for effective thermal isolation. Usually, micro-heaters were placed in between Silicon of oxide compounds or Nitride compounds.

The power consumption of heater can be calculated with the help of the formula which was shown below

$$P = \frac{V^2}{R} \qquad (1)$$

V represents voltage applied

R represents the resistance between two micro-heater ends

$$R = \rho \frac{l}{w \cdot h} \qquad (2)$$

ρ determines the resistivity of the material used for heater,

l is the length of the heater,

w is the width of the heater,

h is the height of micro-heater.

Resistance of the gas can be achieved by using the formula

$$R_{gas} = R_{air}/(a + b \cdot C) \quad (3)$$

Where Rair = resistance of the gas sensor in air (Initial resistance)

Rgas =Steady resistance of the sensor by subjecting to the sensing gas.

C = concentration of the gas.

a and b are the constants

By detecting the resistance of the sensor, it is possible to detect the current gas concentration.

The temperature estimation formula for the micro heaters which are designed by Pt electrodes is

$$T = (R - R0)\text{-}(\alpha R0) + T0 \qquad (4)$$

Where T0 =room temperature,

R0 =original resistance

at T0, and (α=0.0022) is the coefficient of temperature resistance of Pt but during our simulation we assumed that

The resistivity of platinum which is used as electrode can be defined by:

$$\rho = \rho0\,(1 + \alpha\,(T - T0)) \qquad (5)$$

Where ρ0=original resistivity of Pt which can be calculated from R0.

The distribution of temperature along length of cantilever can be obtained by defining the maximum temperature. The temperature along the length of the beam can be represented as T (l, Tmax). The resistivity along the beam ρ (l , Tmax) can be calculated from:

$$\rho\,(l, T_{\max}) = \rho_0\,(1 + \alpha\,(T\,(l, T_{\max}) - T_0)) \qquad (6)$$

The maximum operating temperature resistance will be estimated from:

$$R(T_{\max}) = \int_0^{L_p} \rho\,(l, T_{\max})/S\;dl \qquad (7)$$

Where Lp is the total path along the length of beam.

Table 2: Material Properties used for Elements mentioned

Materials	Thermal Conductivity K[W / (m * K)]	Heat Capacity C_p [J / (kg * K)]	Young's Modulus E[P_a]	Poisson's Ratio	Coefficient of Thermal Expansion α [1/K]
Si	130	700	$170e^{9}$	0.28	$2.6e^{-6}$
SiO2	1.4	730	$70e^{9}$	0.17	$0.5e^{-6}$
Si_xN_4	20	700	$250e^{9}$	0.23	$2.3e^{-6}$
Pt	71.6	133	$168e^{9}$	0.38	$8.8e^{-6}$

4. RESULTS AND DISCUSSIONS

I. GAS SENSOR WITH A RECTANGULAR CANTILEVER:

The following plots explains about the temperature distribution over width, depth and height of gas sensor the Fig.3 shows the thermal image of the sensor with rectangular cantilever which provide information about the hotter and relatively cooler areas.

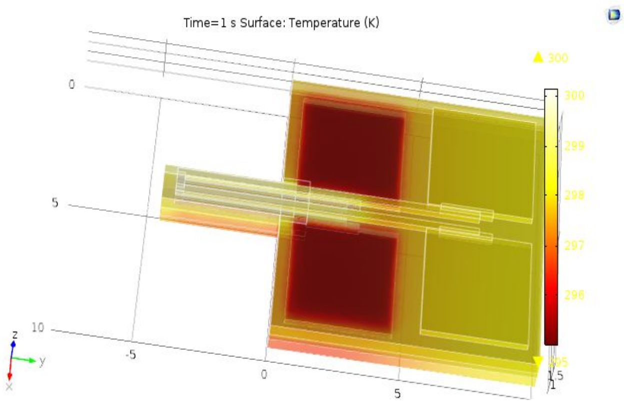

Figure 3: Thermal image of Gas Sensor with rectangular cantilever

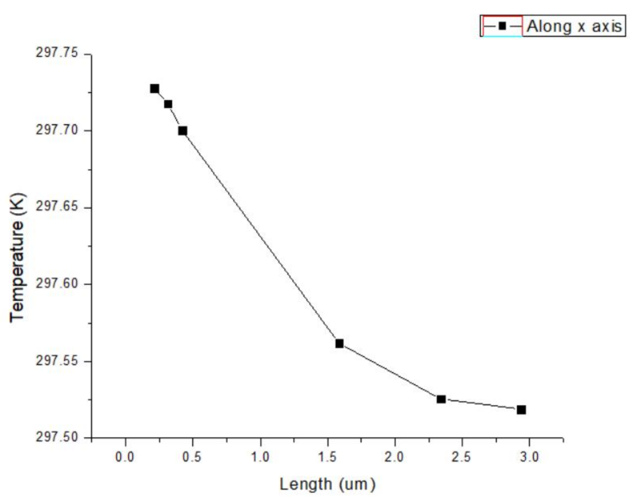

Figure 4: Temperature distribution along width of the sensor

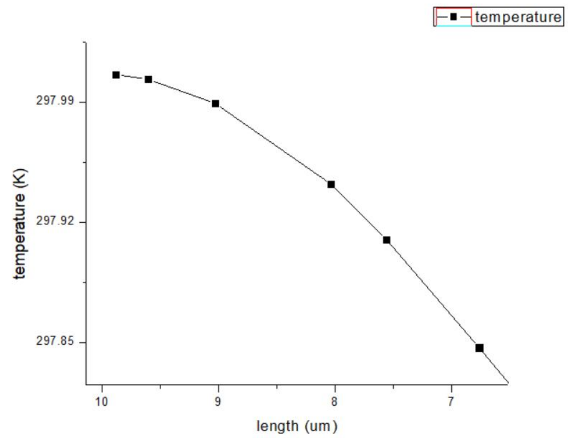

Figure 5: Distribution of Temperature along depth of the sensor

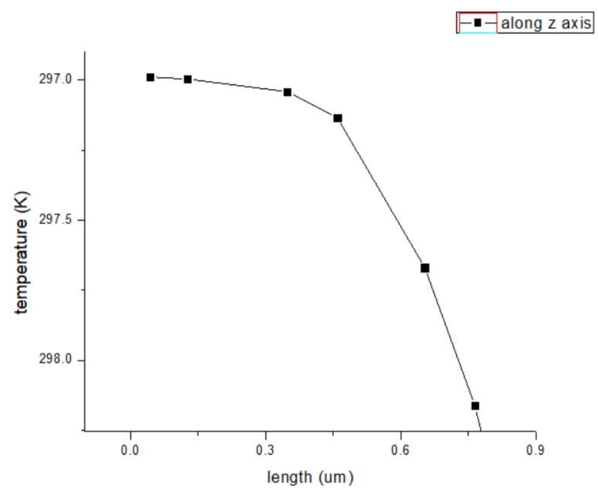

Figure 6: Distribution of Temperature along height of the sensor

From the above graphs the temperature at the cantilever is high compared to remaining portions of the sensor. This temperature is sufficient for the reaction of gas on the cantilever.

II. GAS SENSOR WITH A CYLINDRICAL CANTILEVER:

Instead of using rectangular cantilever, a cylindrical cantilever is designed to observe the response time of the sensor. The following plots explain about the temperature distribution over width, depth and height of gas sensor.

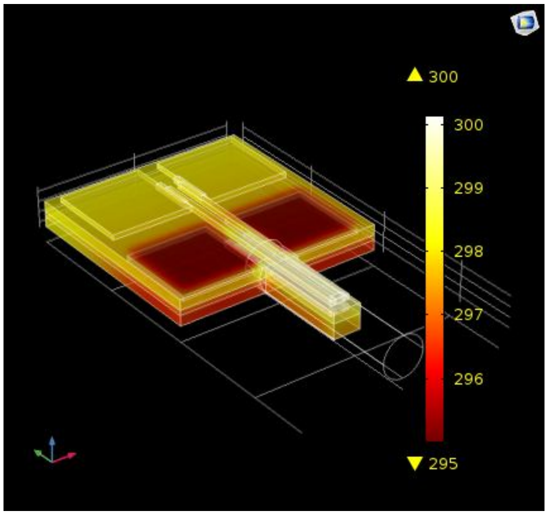

Figure 7: Gas Sensor with cylindrical cantilever

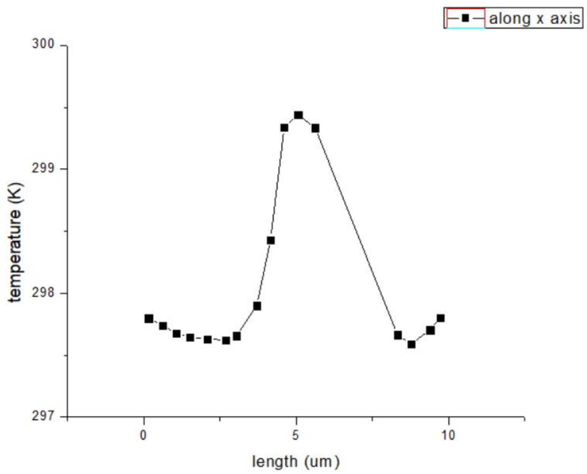

Figure 8: Distribution of Temperature along width

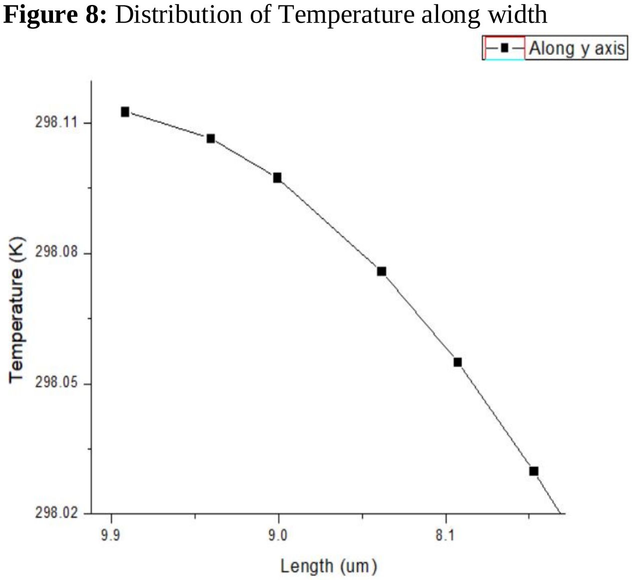

Figure 9: Distribution of Temperature along depth

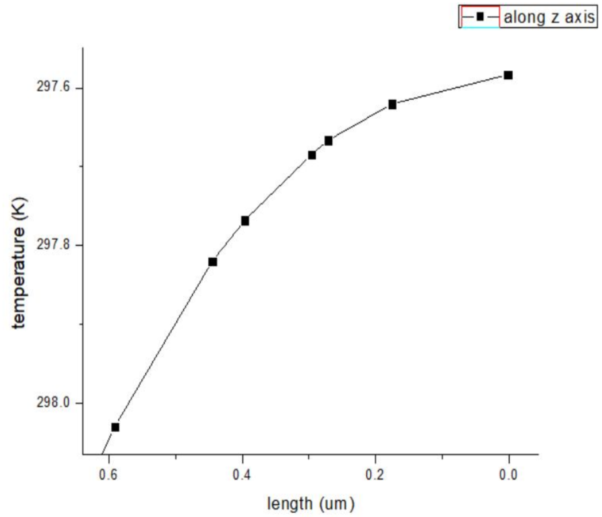

Figure 10: Distribution of Temperature along height

III. RESPONSE TIME VS CONCENTRATION

By comparing these two results we can say that the response time of the rectangular cantilever is less than the cylindrical cantilever. This is due to the lack of air flow over the sensing material.

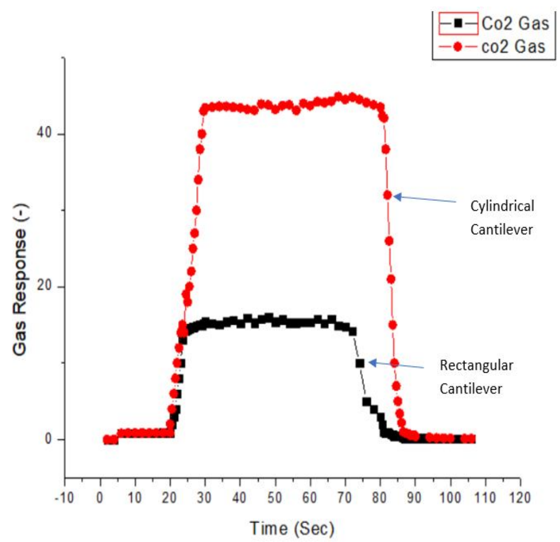

Figure 11: Comparison of Response time of Co2 with sensors of different cantilevers.

Cylindrical cantilever responds when the medium consisting of high ppm of co_2 as, in case of rectangular cantilever it will respond even for low ppm of gas.

IV. RESISTANCE VS VOLTAGE

As it reaches the cutoff voltage, the sensor material, senses the gas which results in the variation of resistance. The resistance decreases gradually after introducing co_2 as shown in the figure12.

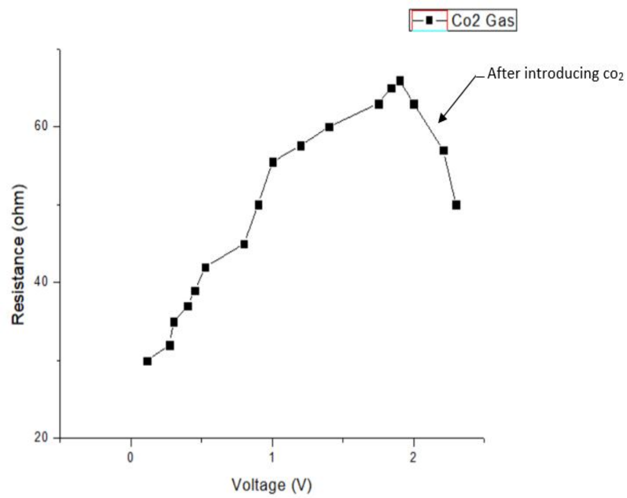

Figure 12. Resistance Vs Voltage

5. CONCLUSION

The resistance of the sensor is reduced over higher concentrations of carbon dioxide (CO2), Due to this Ra /Rg Ratio will give high value this is because resistance of the gas sensing material reduces. This phenomenon is due to increase in the density of electrons correlated with CO2 molecules, this reduces the resistance of the sensor. figure11 Displays the simulated sensor response results varies from 0 to 60 ppm CO2. For the two types of cantilevers. from the figure11, the concentrations above 60 ppm doesn't impact the response of the sensor, it shows that, the vacancy sites present in SnO2 film were quickly filled and those sites will be completely saturated because of O− or O−2 ions present at lowconcentrations

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