PEIZORESISTIVE MEMS CANTILEVER BASED CO_2 GAS SENSOR

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Abstract

A study about the piezoresistive Micro-Electro-Mechanical Systems (MEMS) cantilever for a chemical sensitive - mass based sensor has been carried out to enhance sensor sensitivity. The sensitive region attracts the CO_2 molecules there by introducing the stress concentration region (SCR). Three types of SCR geometry designs were first analysed using Intellisuite software to study the effect of stress and its distribution when varying mass is applied at the SCR. The results showed that the rectangular SCR design has the highest stress. Then, the length of rectangular SCR is varied to study the stress distribution along the cantilever. The piezoresistive element was then placed at various positions to obtain the highest stress resulting due to the deflection of the cantilever. The impact due the SCR was also analysed. The testing results of this piezoresistive MEMS cantilever with rectangular SCR had successfully enhanced sensitivity times as compared to the piezoresistive MEMS cantilever without SCR when varying mass is applied. Therefore this SCR approach appears to be suitable for enhancing the sensitivity of a mass-based piezoresistive MEMS cantilever sensor.

Key words: MEMS, chemical cantilever, peizoresistivity, stress, deflection, sensitivity

I.INTRODUCTION

The most prominent greenhouse gases in the Earth's atmosphere are water vapor, carbon dioxide, methane, nitrous oxide, ozone and CFCs. The alarming increase among these gases is that of CO_2 and is a silent killer. Hence a sensor to monitor the quantity of CO_2 molecules is necessary leading to this paper.

Miniaturization has gained enough significance as specified by Moores Law. The recent Micro-Electro-Mechanical Systems (MEMS) research efforts focus on several converging areas of science and technology such as biotechnology and health sciences. Brugger et al. (3) have pointed out that the cantilever sensor is the simplest device among MEMS devices that offers a very promising future for the development of novel physical, chemical and biological sensors. The small size of MEMS allows for the construction of arrays of hundreds of sensor devices on a single substrate. By being capable of producing thousands of devices on each individual silicon wafer, the cost per unit can be driven down to affordable prices (1,2).

The bending of the cantilever is related to the applied mass or molecular substance that binds on the surface. The bending produces two effects 1) It changes the orientation of the cantilever surface with respect to the horizontal surface 2) It produces surface stress and hence strains. This stress could be converted to resistance and then converted to an equivalent voltage using a bridge circuit.

Several available detection methods have been used in the literature such as capacitance, optical and piezoresistive methods. The complicated capacitive system setup and laser heating effect of the optical laser (3) has led to the selection and use of the piezoresistive method for the current study. Highly sensitive sensor devices are desired in many applications to increase the performance of detection. A sensor's sensitivity indicates how much the sensor's output changes when the quantity measured changes. This is owing to the small detection of biological mass to allow for readable results to be amplified. Instead of scaling down the device geometry (3,4), some studies have published many other approaches aimed at increasing the sensitivity of the MEMS cantilever. These approaches include changing the material used for cantilever structure that has a low Young's modulus by using SU-8 polymer (5) and amplifying the readout systems (6).

Among the increasing sensitivity approaches, introducing stress concentration region (SCR) seems to be the most suitable approach in increasing the sensitivity of MEMS cantilever since the piezoresistive detection is highly dependent on stress occurred at the cantilever. Yu et al. (7) introduced holes to the beam in their simulation analysis to study the effect of

Subhashini. S. et al: Peizoresistive MEMS Cantilever Based CO_2 Gas Sensor 3 surface stress on the sensitivity of MEMS cantilever. He and Li (8) studied surface stress effect on various types of SCR holes and a number of holes using ANSYSw. They found that adding more holes to MEMS cantilevers did not help to enhance the surface stress. Bhatti et al. (9) also completed similar studies and confirmed the findings that only one hole is sufficient to optimise the surface stress.

In this Paper, the SCR approach is taken to enhance the selectivity and sensitivity of the MEMS cantilever, and two types of piezoresistive MEMS cantilevers were designed and fabricated: the first is a piezoresistive MEMS cantilever without SCR and the second is a piezoresistive MEMS cantilever with rectangular SCR, since they can easily compensate for the environmental changes, in a wheatstone bridge. The proposed SCR designs are analysed using Intellisuite software to predict the design parametric study.

II. STRUCTURE OF THE PROPOSED SYSTEM

The main objective is to selectively choose the CO_2 molecules from the mixture of gas molecules present in the atmosphere. This selection is done by using a polymer coating on top of the cantilever. The sensor designed for achieving this is as shown in Fig. 1. In Fig. 1(a) the sensing cantilever structure is shown and here we can see that a polymer coating is at the end to create the resistive changes based on the quantity of CO_2. The gaseous inlet from the atmosphere is given to the entire setup and this exposure lets the CO_2 molecules to be selectively adsorbed and thereby increasing the mass of the cantilever. This increase in mass results in a stress near the fixed end and could be sensed using a peizoresistive element placed there and which will form an arm of the wheatstone bridge as shown in Fig. 2. This change in mass of the cantilever due to the CO_2 molecules adsorption results in a change in the resistance thereby resulting in the bridge imbalance giving a voltage output. This change in voltage is noted and can be interpreted with the quantity of CO_2 molecules adsorbed and hence the quantity of CO_2 present in the atmosphere.

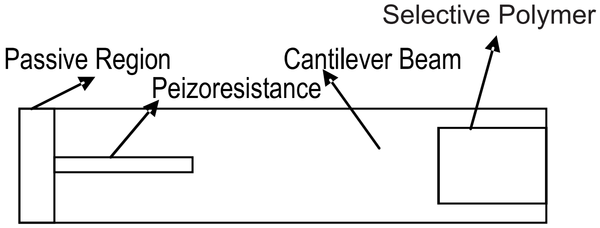

Fig. 1(a). The basic sensing cantilever structure

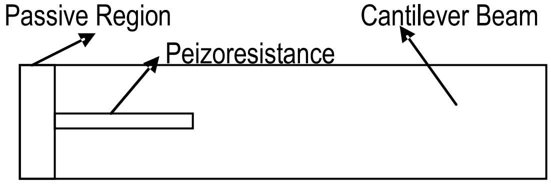

Fig. 1(b). The basic reference cantilever structure

The wheatstone bridge setup is a well known one to find the resistance change. The change in piezoresistor is linearly related to the applied stress and the strain developed (9,11,12). The resistance change is found using the bridge circuit made up of a combination of four peizoresistors as shown in Fig.2. Initially when no CO_2 molecules are adsorbed the bridge is balanced giving out zero output voltage. This implies that the reference cantilever's peizoresistor equals that of the sensing cantilever's peizoresistor, this is advantageous as the environmental effects can be neutralized. Later as the CO_2 molecules get adsorbed on the surface the mass of the cantilever increases and thereby deflects from its initial position resulting in a strain. The peizoresistor of the sensing cantilever thereby changes resulting in a imbalance of the bridge and hence produces a voltage.

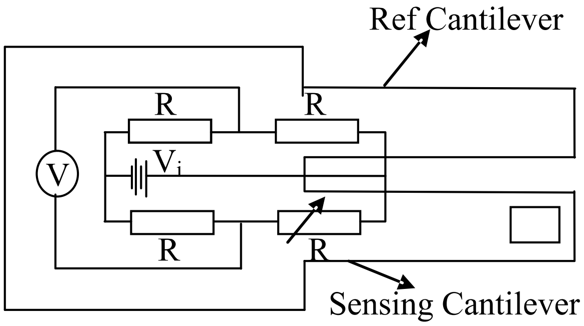

Fig. 2. The wheatstone bridge circuit with the reference and sensing cantilevers

III. FABRICATION STEPS FOR THE PEIZORESISTIVE GAS SENSOR

The simulation study was conducted for the peizoresistive sensor using the Intellisuite software. The fabrication of the sensor was done effectively using step by step process of deposition and patterning using proper mask layers and definitions and etching process. It is at this stage where the size of the cantilever, the sensing area and the peizoresistor are defined. Surface micromachining and bulk micromachining methods are employed in patterning. The stepwise process followed is given below.

1. Define Si <100>
2. Deposition of SiO_2
3. Deposition of Photoresist (PR-S1800)
4. Definition of UV
5. Partially Etch Photoresist
6. Partially etch SiO_2
7. Partially etch the photoresist
8. Deposition of Poly silicon
9. Deposition of photoresist
10. Definition of UV
11. Etch through photoresist
12. Etch through Poly silicon
13. Partially etch photoresist
14. Deposition of silicon
15. Deposit Si_3N_4
16. Deposit photoresist
17. Definition UV
18. Etch through photoresist
19. Etch through Si_3N_4
20. Partially etch photoresist
21. Etch polysilicon

The sensor thus efficiently fabricated is exported to the thermo electro mechanical analyser where the various analysis are done to study the effective performance. The final product will resemble fig.2.

IV SIMULATION RESULTS

The fabricated sensor after being transferred to the Thermo Electro mechanical Analyser is now fit to take up the boundary conditions and the inputs.

Proper meshing is done to save time and in the meantime not to miss out the values. Hence the optimisations are done to have a better selectivity and sensitivity.

A. Mesh sizing:

Mesh size determines the analysis segment. This implies as the mesh size decreases the execution time will be more and vice versa. In the mean time inorder to reduce the running time if we go in for increased mesh size sometimes depending on the process we might loose some minute important datas, this can not be tolerated. Hence we will have to obtain an optimum mesh size to efficiently run the process. Few theoretical calculations were made and compared with the simulated response to get the optimum settings. Fig.3 illustrates the relation between the mesh size and the displacement for the same sized cantilever, boundary conditions and input. It was observed that when the mesh size was 80 the theoretical results matched with the simulation results and it was also observed that the linearity criteria was fulfilled about that region. Hence 80 was choosen as the mesh size.

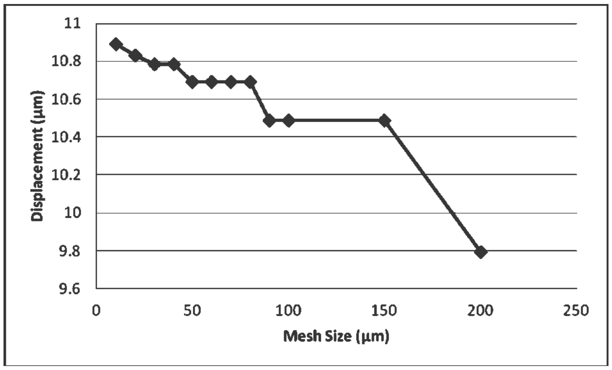

Fig. 3. Characteristic curve to determine the mesh size

B. SCR Design

The sensitive area plays an very important role in the determination of the CO_2 quantity. Hence few shapes were considered and the best option is considered further as an ideal shape. Fig. 4 shows the placement of the sensitive layer.

Having designed the shapes the input pressure is applied and the maximum displacement produced by the cantilever is measured and plotted. From the graph it is seen that the rectangular shaped SCR produced more linear effect and hence we shall stick on with rectangular SCR. This is visualized in Fig. 5.

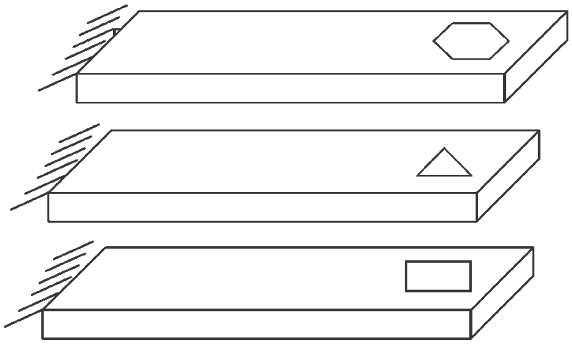

Fig. 4. Cantilever with various SCR Design

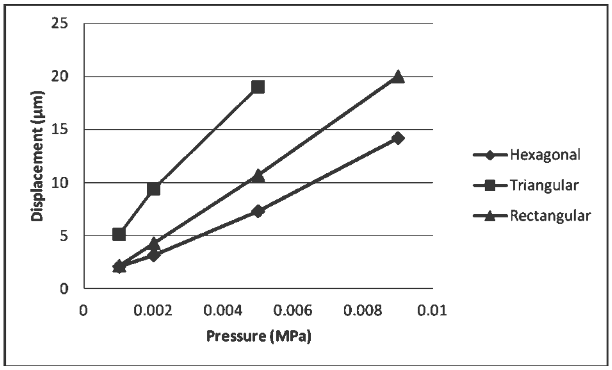

Fig. 5. Pressure applied vs the displacement produced for the various shapes of SCR

C. Thickness of cantilever

The thickness was varied and was found the the displacement got saturated when the thickness was less than 5 microns and the sensitivity got reduced when thicker cantilever was used hence and optimum 10 micron thick cantilever was used.

D. Positioning of Peizoresistor

Peizoresistors were placed in various positions and the resistance formed was analysed and the optimum positioning is shown in Fig.1

E. Pressure – Displacement Curve:

The linear relation between the input and output is observed and is shown in Fig. 6

F. Pressure – resistance Curve:

From Fig. 7 we can notice the linear relation between the input pressure and the peizoresistance change. Sensitivity is 840 ohm/MPa.

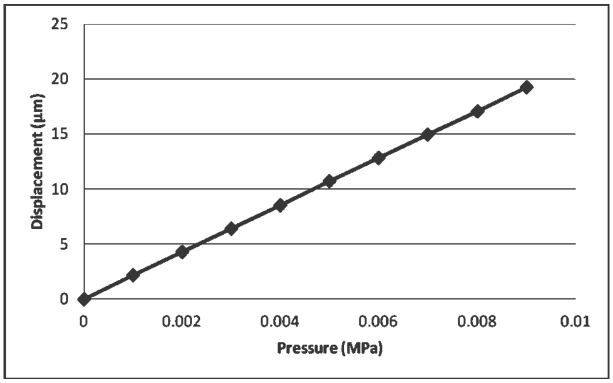

Fig. 6. Input – Output relation of cantilever

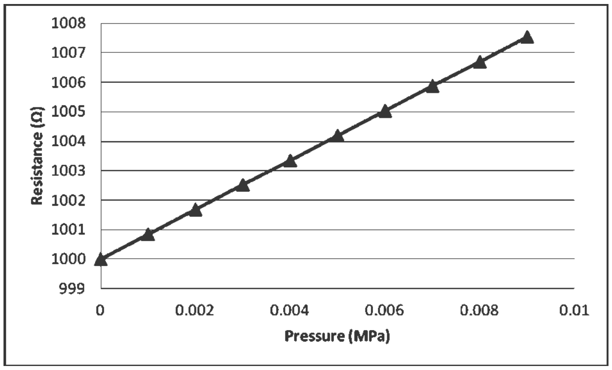

Fig. 7. Input Pressure and the Peizoresistance Characteristics

G. Pressure – Voltage Curve

The ultimate output of the sensor is the output of the wheatstone bridge i.e the voltage. From Fig.8 it could be observed that there is a very good linear relation between the input pressure and the output voltage. The sensitivity is also in the range of 840mV/MPa. This is a good sensitivity range for a sensor.

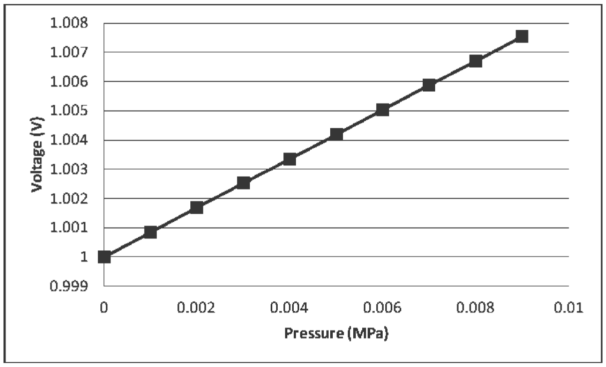

Fig. 8. Input Pressure and the bridge output voltage Characteristics

V CONCLUSION

We have thus designed a CO_2 sensor having a cantilever with rectangular SCR for sensing and the thickness is 10micron and the mesh size used for analysis is 80 microns. A peizoresistor was incorporated in the most stressful area and the resistance change was studied using a bridge circuit and an equivalent voltage was obtained. The simulated results were compared and studied. This sensor could prove to be a handheld device.

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