



A cantilever based MEMS sensor for detection of greenhouse gases

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ABSTRACT

In the past two decades global warming was being caused by rising absorptions of greenhouse gases (GHG) composed by human activities. Greenhouse gases catch heat in the atmosphere, which makes the earth warmer. The effect of greenhouse gas is the process by which absorption of cantilever beam by gases in a planet's atmosphere warms its lower atmosphere and surface. The main aim of this paper is finding the essential conditions of the warming issues caused by different GHG which are rising at an undisciplined rate. This paper desire in decision out an approach to quantitatively evaluate the unsafe gas molecules. Analysts gases are absorbed by a sensitive ZnO layer deposited on the cantilever. A model has been developed to describe the dependence of the gas sensor on the thickness of the ZnO layer. The type of gravimetric sensor works by arresting the chemical in a absorbers compound, which is changes an overall group of the sensing aspect i.e. a cantilever, and its displacement. Hence, the cantilever sensing layer is being constructed using a selective layer on the surface area to carefully consume the unsafe gases. In this paper different geometry of cantilever beam such as rectangular type, rectangular beam with four repeating square holes and step profile which are designed and simulated using the finite element software INTELLISUITE 8.7. The simulation results show that the

rectangular beam with four repeating square hole geometries have been the more deflection at same the displacement of the conventional beam and also increasing the sensitivity.

Keywords: Micro-Electro-Mechanical System, Cantilever, Green House Gas (GHG), Displacement, Sensitivity.

1. INTRODUCTION

The discharge of different chemical contaminants from industries, homes and automobiles into the air has been producing the global environmental problems such as acid rain, the greenhouse issue and ozone deficiency of the gases are NO_x, SO_x, HCl, CO₂, CH₄, N₂O, O₃ etc. In this paper have micrometer-sized cantilevers dominance agreement as label-free, perceptive, portable, low-cost, highly parallel and rapid sensors for green use and have thus engaged considerable concern from applications such as point of care (POC) diagnostics, motherland security and environmental monitoring and to develop the model sensitivity of cantilevers different designs and proposal have been noted. Mohd Zahid Ansari et al [1] has been discussed in silicon microcantilevers are generally used in MEMS sensor. However, due to high flexible modulus of silicon cantilevers performance is being totally low deflections for a given surface stress change. Asif Mirza et al. [2] microcantilevers have invited users due to their possible in the improvement of many innovative physical, chemical and biological sensors. A.Nallathambi et al. [3] have been analyzed and compared the various microcantilever parameters of the performance like deflection, output displacement and sensitivity. K. Arshak et al. [4] used for the detection of different gases (viz. ZnO, TiO₂, SnO₂) may be used. Yang-Choon Lim et al [5] have been pointed out that the microcantilever sensor are the device among MEMS that offers a very encouraging ultimate for the advancement of physical, chemical and biological sensors. Sugato Ghosh et al. [6] however the three key aspects which are answerable for the detection of particular gas factors of the variety of gases. They are divided into three categories (1) Temperature of the sensing material (2) Response time and (3) Recovery time of the sensor. Among these, the temperature of sensing material is one among the important factors for the detection of a particular gas. The method of cantilever operation can be assigned either static or dynamic depending upon the parameter measured. Rosminazuin Ab. Rahim et al [7] was focused on the higher mechanical sensitivity advantage to a larger surface-stress-induced bending of the cantilever which results in higher sensor achievement and sensitivity. Rosminazuin Ab. Rahim et al. [8] finite element model was advanced to analyze electrical and mechanical response of the piezoresistive microcantilever in enhancing the sensor sensitivity. Nickolay V. Lavrik et al. [9] was discussed in the absence of external gravitational, magnetic, and electrostatic forces, cantilever deformation was unambiguously related to a gradient of mechanical stress developed in the device. S. Capone, et al.[10] have been measuring the greenhouse gases is an essential task in many fields, including , process control, environmental monitoring, medical instrumentation in the earth's atmosphere are water vapor, carbon dioxide, methane, nitrous oxide, and ozone gases.

The advancements of gas sensors are to observe different greenhouse gases. However, the task is being formidable and demanding. There are a number of solid-state gas sensors are applicable for detecting the gaseous components nearby in nearly large concentrations, such as CH₄, CO₂, N₂O and O₃.

2. DESIGN OF GAS SENSOR

MEMS are micro devices that are advanced using approaches from integrated discrete processing. The capabilities of MEMS include mechanical, thermal, fluidic, and electrical parameters were analysed. They are small in size implements with their use in applications which are inaccessible to conventional devices, and there can often be performance advantages due to favorable scaling effects as well. The MEMS cantilever gas sensors adventure the surface-stress convinced deflections due to measurement and the object molecules. When the objects particle connects onto the functional and dominant outside of the MEMS cantilever, the outside stress circulation on this surface is interchanged, appearing in a differential stress crosswise the top and base outsides of the microcantilever. The differential stress basically produces bending in the MEMS cantilever.

The first model of gas sensor as rectangular profile microcantilever in the displacement (Figure.1a) and the differential outside stress ($\Delta\sigma$) are related by the Stoney Equation [1] is given as:

$$\Delta z = \frac{4(1-\nu)\Delta\sigma}{E} \times (l_0 / t_0)^2 \quad (1)$$

Where l_0 is the length of the cantilever and t_0 is the thickness of the cantilever. Then E and ν are the young's modulus and Poisson's ratio of the cantilever beam material.

In the second model of the cantilever adsorbate-induced deformations of thin plates can be perfectly predicted using a conversion of the relationships basically derived by Stoney equation [5] :

$$\frac{1}{R} = \frac{6(1-\nu)\Delta\sigma}{Et^2} \quad (2)$$

Where R is radius of curvature in microcantilever, E and ν are Young's modulus and Poisson's ratio for the substrate respectively. t is the thickness of the cantilever and $\Delta\sigma$ is the differential surface stress. Knowledge of the radius of curvature R allows the tip displacement of a rectangular beam with four holes [5]

(Figure. 1b) microcantilever to be determined by

$$\Delta z = \frac{1}{2} \frac{l^2}{R} = \frac{3(1-\nu)\Delta\sigma}{E} \times (l_0/t_0)^2 \quad (3)$$

In the third model by using Euler beam theory as well as fundamental of superposition for nonprismatic beams [1], a step profile cantilever of the Stoney equation (Figure 1c) can be modified as given:

$$\Delta z = \frac{4(1-\nu)\Delta\sigma}{E} \times \left[\left(\frac{l_0}{t_0} \right) + \frac{(3l_0 + 2l)l^2}{2t^3} \right]^{\frac{2}{3}} \quad (4)$$

Where l and l_0 are the lengths of the cantilever t and t_0 thickness of the cantilever

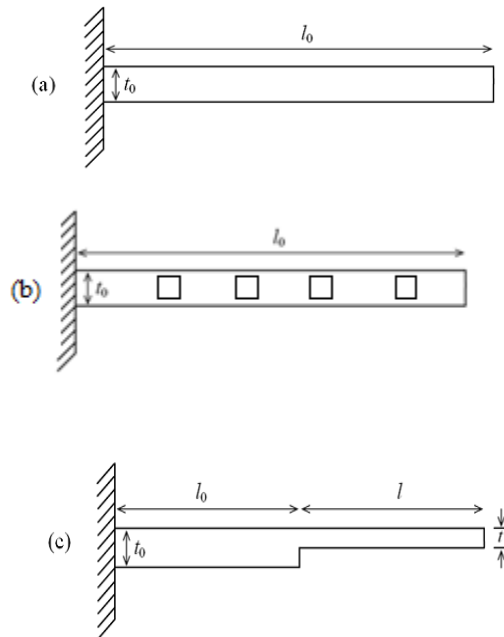


Figure 1

Schematic design of (1a) Rectangular, (1b) Rectangular beam with four repeating square holes placed in the middle and (1c) Step profile cantilevers produce holes, i.e. producing charge carriers.

3. MODE OF OPERATIONS

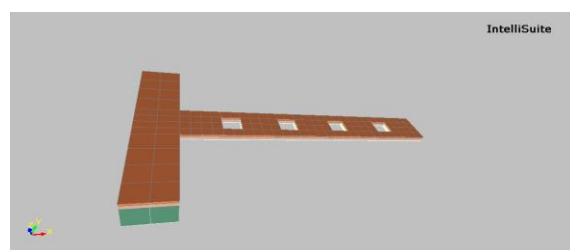
The adsorption of mass equivalent respect over a beam surface can lead to modifies in the cantilever deflection is as shown in below results. The detection of this feedback is normally indicated as static modes of operation respectively. The static mode effective principle is the bending begins as an effect of a surface stress modifies convinced by each molecular reaction and which takes place

on only one of the cantilever surfaces. The convinced surface stress vary can be positive or negative, depending on the surface deformation developed.

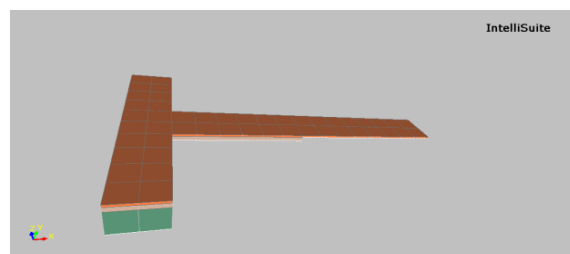
This paper explains a latest technique of measurement of the greenhouse gases specifically methane, carbon dioxide, nitrous oxide and ozone. These gases have different densities so for a reference volume they have different mass values. Here, in this work taken the mass equivalents of these gases which cause corresponding displacement of the cantilever. It is used an ideal gas law to find the mass equivalent to pressure equivalent value of gases.



2(a)



2(b)



2(c)

Figure 2

Observation between the basic and modified design of (2a) Rectangular cantilever, (2b) Rectangular cantilever with four repeating square holes placed in the middle and (2c) Step profile cantilever.

The appreciating method is that an exact binding convinced surface stress elements bending of the realizing cantilevers. Currently the study is accommodating the Si_3N_4 cantilever with a choosy membrane coat for the analysis of greenhouse gases. The sensing layer is generally used as ZnO. The temperature is controlled to improve the selective method. Thus the outside area had to be enhanced for improved sensitivity. It has more advantages to the use of porous polymer material. However, this porous environment produces the plan also difficult as they are graceful and experiment to exclude the molecules will start to the explosion of porosity. Thus the special care should be appropriated in the scheming condition. Due to the statement that the gas particles are adsorbed so there will be stress seated due to development in weight which starts to modify in the displacement of the cantilever.

Much of the research focus on the MEMS area is on the fabrication of MEMS devices. The fabrication techniques are directly related to very large scale integration (VLSI) technology. Materials and methods compatible with silicon technology and required electro-mechanical material properties are being considered. Our focus is on simulation of MEMS performance where the different structure shapes and material properties are used as inputs to expect the performance. The ultimate target of this research is to develop simulators to permit better considerate of MEMS behaviours, and facilitate in the design and fabrication of MEMS to reach optimal performance.

4. OPTIMIZATION OF THE PROPOSED STRUCTURE

The typical detailed microcantilever dimensions are used as the length 140 μm , width 20 μm and around 5 μm thickness. When the design of MEMS cantilever based sensors, it is essential to consider and optimize the cantilever element that gas observing sensor sensitivity

Table 1

Properties of Material and Dimensions

Layers [Material]	Dimensions (μm)	Material Property		
		Young Modulus (Gpa)	Poisson Ratio	Density (gm/cc)
Substrate [Silicon]	20 \times 100 \times 10	170	0.26	2.32
Structural Layer [Si ₃ N ₄]	140 \times 20 \times 2	296	0.275	3.1
Sensing Layer [ZnO]	140 \times 20 \times 1	140000	0	0

A. Length

The cantilever beam length is being varied and its maximum displacement was achieved. It is realized that even for a considerable span of length changes the sensitivity remain constant specifically in the region between 50 μm to 140 μm . Hence a maximum length of 140 μm was considered for the design.

B. Thickness of beam

The MEMS cantilever beam thickness is being varied and its displacement was achieved. It is realized that the return is linear and so a thickness of 3 μm is measured for the design.

5. CANTILEVER DISPLACEMENT MEASUREMENT

The sensor consists of two peripherals- sensing layer and transducer i.e. cantilever. The sensing layer is the challenging basic and it mechanically performs to mass change. Hence if there is superior deposition of gases there will be more variation in the displacements. By comparing the variations, the efficient number of the cantilever prior to and after risk is determined. The change between these two evaluations would be pointed out to the amount and the environment of the gas to which the cantilever is solved.

6. SIMULATION RESULTS AND DISCUSSION

The output of different gases displacements is tabulated and is shown in Table-II. In this work is found the maximum output displacement in the model 2 (rectangular with four holes beam), which is suitable for gas sensing devices.

In the first model simulation, the dimension of length and thickness of the cantilever beam is set at 140 μm and 3 μm , respectively, at the same time width of the beam is 20 μm . The simulation results are obtained in Fig. 3(a)-6(a). It can be an experience that as the cantilever beam length an enhanced, larger displacement is generated.

In the second model simulation, the dimension of cantilever beam length and width are fixed at 140 μm and 20 μm , respectively. Also, the beam thickness is similar as 3 μm using parametric study purpose as shown in Fig. 3(b)-6 (b).

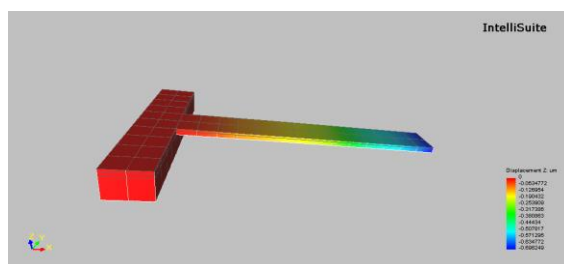
Table 2

GHG	Mass Eqvt. (gm)	Pressure Eqvt. (MPa)	Model 1 Dis-placement (μm)	Model 2 Dis-placement (μm)	Model 3 Dis-placement (μm)
CH ₄	0.071	0.1747	0.6982	0.7806	0.7061
	0.179	0.4367	1.7469	1.9527	1.7713
	0.357	0.8732	3.4941	3.9056	3.5427
	0.714	1.7470	6.9916	7.8148	7.0886

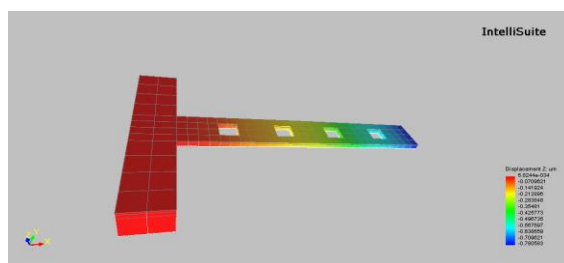
CO ₂	0.196	0.4800	1.9202	2.1465	1.9471
	0.490	1.2000	4.8029	5.3676	4.8688
	0.980	2.4000	9.6053	10.7362	9.7384
	1.960	4.8000	19.2117	21.4735	19.4777
N ₂ O	0.198	0.4851	1.9407	2.1693	1.9678
	0.495	1.2120	4.8052	5.4213	4.9175
	0.990	2.4250	9.7054	10.8481	9.8399
	1.980	4.8510	19.4158	21.7016	19.685
O ₃	0.214	0.5243	2.0976	2.3446	2.1268
	0.535	1.3100	5.2425	5.8597	5.3152
	1.070	2.6210	10.4899	11.7250	10.6353
	2.140	5.2430	20.9849	23.4554	21.2754

In the third model simulation, the extent of the beam length and width of the dimensions is fixed at 140 μm and 20 μm , respectively. Equally, the thickness of the beam is varied as 3 μm and 1 μm using step profile cantilever as shown in Fig. 3(c)-6(c). Unlike in the earlier simulation by which the beam's displacement is compared to the length of the cantilever, the displacement in the second simulation modified as the structure of the cantilever beam and has been maximum displacement compared with the other two models. Four different gases were analyzed such as CH₄, CO₂, N₂O and O₃. Among there ozone gas was achieved maximum displacement.

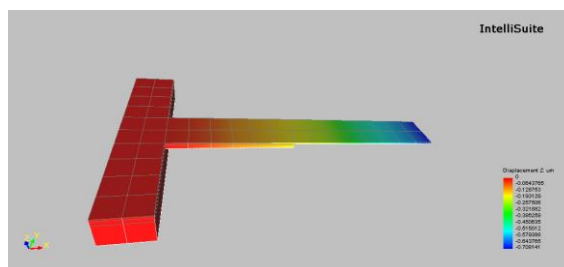
1. Methane Gas



(a)

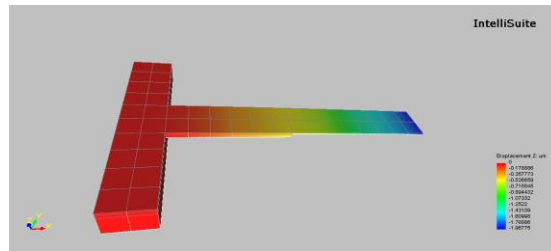


(b)



(c)

Figure 3
Output Displacement for Pressure Eqvt. of 0.1747 Mpa

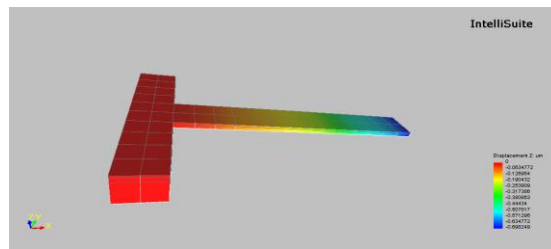


(c)

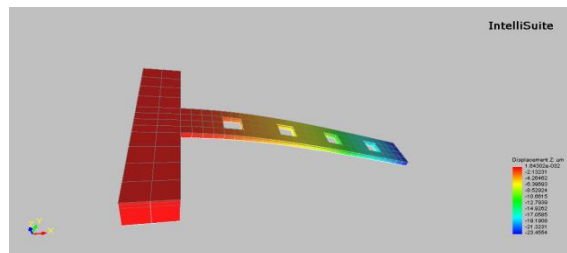
Figure 5

Output Displacement for Pressure Eqvt. of 0.48510 Mpa

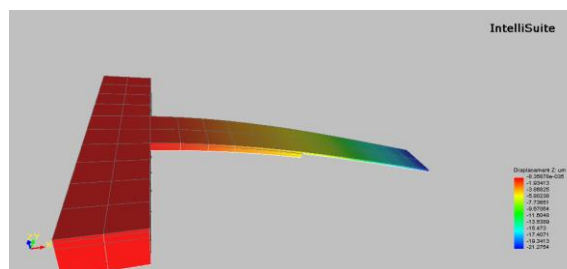
4. Ozone Gas



(a)



(b)



(c)

Figure 6

Output Displacement for Pressure Eqvt. of 5.2430 Mpa

7. SENSITIVITY OF GREEN HOUSE GASES

The Table II as shown as observed that simulation principles for the entire cantilever types and equivalent results, representing the consistency of the simulation and Sensitivity obtained from INTELLISUITE. Figure 7-10 illustrates the simulation end result and sensitivity for the microcantilever intend analyzed in this study.

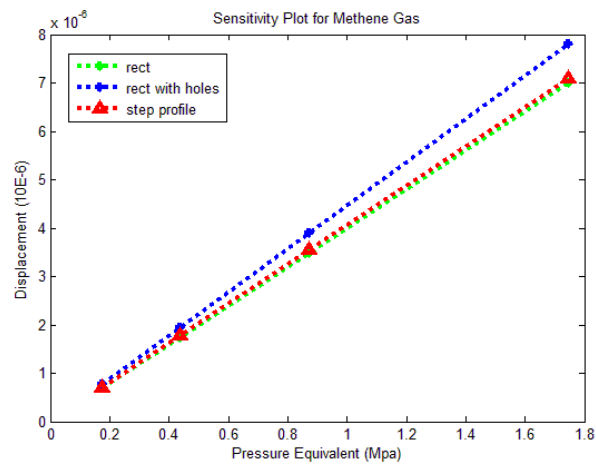


Figure 7
Sensitivity analysis of Methene gas from various shapes

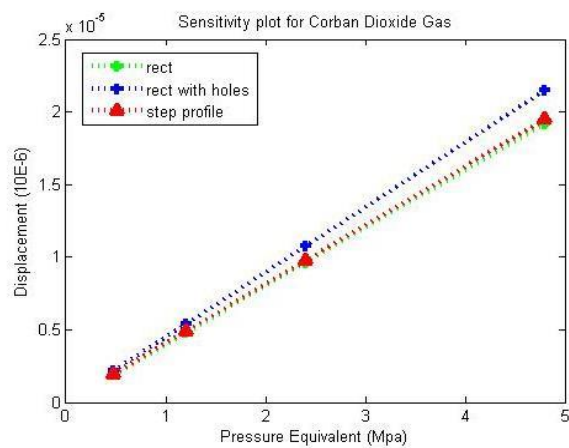


Figure 8
Sensitivity analysis of Corban dioxide gas from various shapes

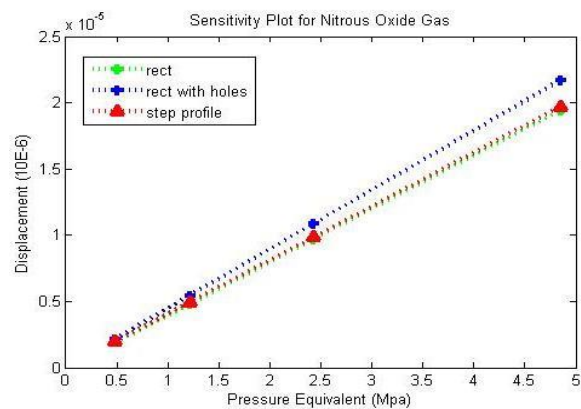


Figure 9
Sensitivity analysis of Nitrous Oxide gas from various shapes

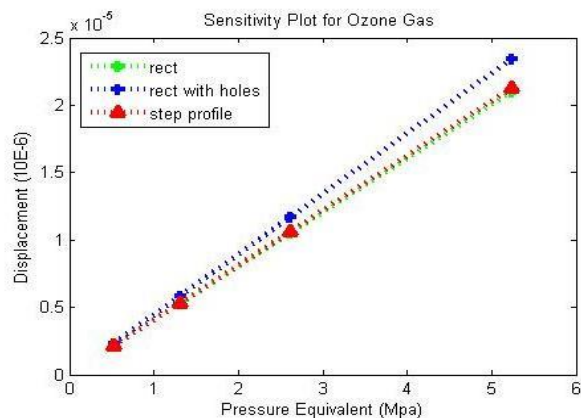


Figure 10
Sensitivity analysis of Ozone gas from various shapes

8. CONCLUSION

The cantilever based MEMS sensor has been designed with three different structures. It is observed that the displacement of cantilever produced, more in the rectangular beam with four repeating square holes shaped cantilever beam structure. In the future nanocrystalline metal oxides would be established the key to the improvement of semiconductor gas sensors with enhanced gas-sensing properties. Not only in chemoresistive gas sensors, but in common in the solid state gas sensors, nanostructure substance will play an essential and a determinant part in the gas sensors of the modern generation. We observe that when the change in mass is high while the change in displacement is also high. Finally the high value of sensitivity is observed from the model 2 cantilever beam structure. This paper could be advanced using the same fundamental to analyze various greenhouse gas molecules.

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