

RESONANCE BASED MICROMECHANICAL CANTILEVER FOR GAS SENSING

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ABSTRACT

Our world is facing some drastic changes in the climatic conditions due to the heating effect caused by various greenhouse gases. The most harmful gas among them is Carbon dioxide and is increasing at an uncontrolled rate.

This paper aims in finding out the quantity of the major polluting gas carbon dioxide. The gravimetric sensor works by adsorbing the CO₂ molecules on ZnO sensing layer, which alters the overall mass of the sensor. The mechanical structure is a cantilever, having its own resonant frequency. To selectively adsorb CO₂ molecules from the mixture of gaseous molecules, ZnO at a specific temperature is used. As the gas molecules are adsorbed the mass increases and hence there is a change in resonant frequency. This change in frequency gives the measure of the quantity of CO₂ molecules present in that environment. The major expected advantage of this technique would be the repeatability of the sensor that is used. This Quantitative analysis of CO₂ would be helpful for mankind by alerting them about the environment in which they work, by proper conditioning and networking.

KEYWORDS

Micro Cantilever, Resonant Frequency, Sensing Layer

1. INTRODUCTION

The term 'greenhouse gases' is used to refer to the gases present in the atmosphere which absorb the radiations and emit them within the thermal infrared range. These gases affect the temperature of the earth significantly, thus the "greenhouse effect" is the heating of the Earth due to the presence of greenhouse gases. The most prominent greenhouse gases in the Earth's atmosphere are water vapor, carbon dioxide, methane, nitrous oxide, ozone and CFCs.

The most harmful gases among them is Carbon dioxide, as its content is increasing in the atmosphere day by day. Carbon dioxide is produced prominently by the respiration of animals, combustion of fossil fuels and geothermal processes, such as eruption of a volcano. Recent estimates reveal, that the concentration of carbon dioxide in the Earth's atmosphere has increased to 387 parts per million by volume. This gas features second in the greenhouse gases list, constituting 9 to 26 percent of greenhouse gases.

Miniaturization has gained enough significance as specified by Moores Law. Hence Micro-cantilevers are increasingly being used for various measurements. They are comparatively

inexpensive, show fast response, have high sensitivity and are suitable for mass production using MEMS technology. Hence there is great interest in micro-cantilever based sensors.

This paper deals with an original methodology of measurement of the major polluting gas carbon dioxide. The gravimetric sensor works by adsorbing the CO₂ molecules in ZnO sensing layer, which alters the overall mass of the sensing element and thereby changing the resonant frequency of the cantilever used. This frequency shift is used to identify the quantity of CO₂ molecules present in the atmosphere. Here a micro-cantilever beam is fabricated using selective coatings on the surface to adsorb CO₂ molecules.

2. SAMPLE DESIGN AND FABRICATION

The sensing scheme is that a specific binding induced surface-stress causes bending of the sensing cantilevers. Present research integrates the SiO₂ cantilever with sensing Layer for the measurement of CO₂. The appearance formed would be as shown below in Fig.1

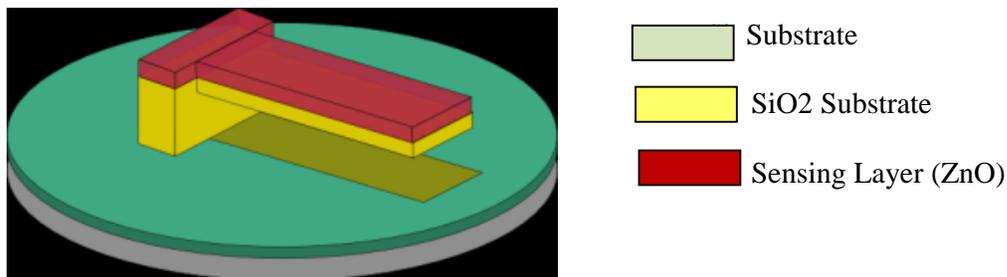


Fig. 1: 3-D Image Of An Integrated Cantilever

2.1. Theory

Micro cantilever is a widely used component in micro system devices. It finds wide range of applications in different fields such as biomedical, consumer products due to its flexibility and versatility. A cantilever is type of beam which is supported and constrained at only one end. Few examples of cantilever include diving board, aircraft wings, balconies of buildings etc.

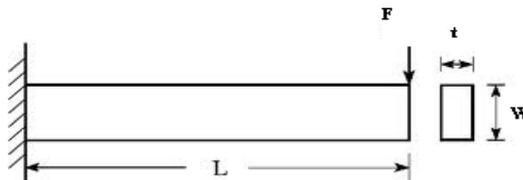


Fig. 2: Simple Cantilever Beam.

Cantilevers come in all sizes. MEMS cantilevers can be as thin as a few nanometers with lengths that range from a few microns to several hundred microns.

Two equations are used to understand the behavior of the MEMS cantilever. The first is the one relating the maximum displacement to the applied force as given below:

$$w_{max} = -\frac{4L^3}{Wt^3}$$

Where w_{max} – maximum deflection (m)
L – Beam Length (m)
W – Cantilever Width (m)
t – Cantilever Thickness (m)

The second is the formula relating the cantilever spring constant K to the cantilever's dimensions and material constants.

$$K = \frac{EWt^3}{4L^3}$$

Where F – Force (in N)
W - Cantilever width (in m)
By Harmonic oscillator formula,

$$\omega_0 = \sqrt{\frac{K}{m}}$$

Where K-Spring Constant
m- Mass (in Kg)
 ω_0 -Cantilever resonance Frequency (in Hz)

Change in force applied to a cantilever can shift the resonance frequency. The frequency shift can be measured with exquisite frequency accuracy using heterodyne techniques and is the basis of ac-coupled cantilever sensor.

The mass sensitivity (S_m) of a cantilever is defined as the change in frequency divided by the mass load. It can be experimentally calculated by the following equation

$$S_m = \frac{\Delta f}{\Delta m}$$

Where S_m - Mass sensitivity

f - Change in frequency
m - Mass load.

2.2. Cantilever Resonance Frequency Measurement for Chemical Gas Sensors

The principle used in this type of sensors is to literally catch gas molecules and to weigh them by measuring the shift in resonance frequency. The chemical sensor consists of two key components: a sensitive layer and the transducer (the cantilever). The sensing layer is the critical component and responsible for selectively capturing the CO₂ gas molecules and the cantilever which acts as the transducer converts the mass into a dynamic shift in the resonant frequency. The Molecular weight of CO₂ is 44 g/mol. The mass change is detected by measuring resonance frequency shifts while actuating the cantilever (dynamic mode). The additional mass load on the cantilever results

in a decrease of the resonance frequency, which is detected. The simulation was carried out using Intellisuite software and the results are graphically represented in Fig. 3.

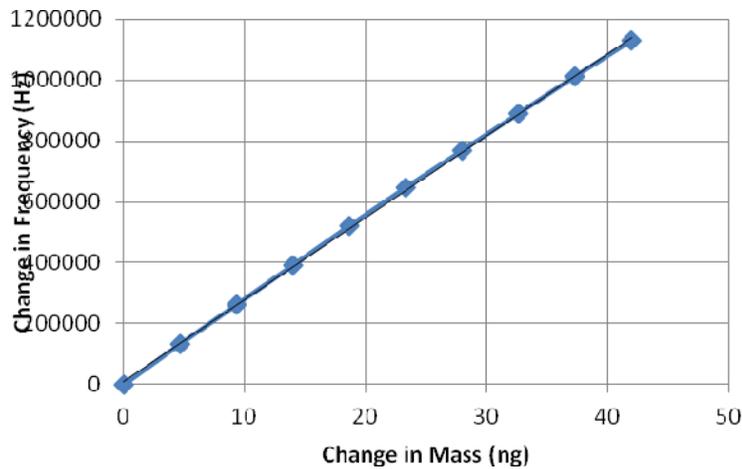


Fig. 3: m to f

It is observed that as the change in mass increases there is a corresponding increase in change of frequency. We can hereby calculate the quantity of gas present in that environment from the resonant frequency we obtain. The frequency is related to mass by

$$f = \frac{1}{2\pi} \sqrt{\frac{k}{m}}$$

2.3. Micro-Cantilever Array

Instead of having individual beams they can be combined as an array as shown in Fig. 4 So as to have a combined response.

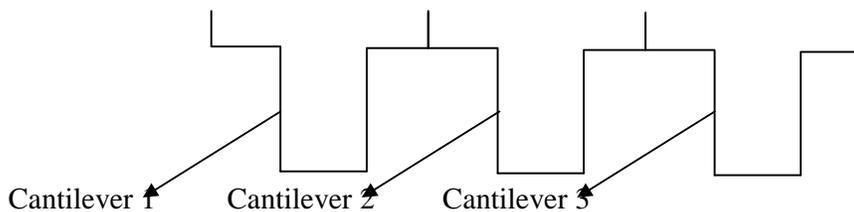


Fig.4: Micro – Cantilever Array

An array of sensors can usually give a better amplified signal which would be of importance and also the selective coating could be varied to give us the quantitative details of N number of gas molecule detection.

2.4. Sensitiveness across the beam

It would be of significance if we could get the maximum frequency change from the change in mass due to the gas being absorbed. For this reason a micro-cantilever of length: 100 μm , breadth: 20 μm and height 10 μm was considered.

The sensitive coatings of length 20 μm and thickness of 0.1 μm was integrated from the tip of the cantilever to the fixed end and the results were simulated using Intellisuite software and the results are consolidated and graphical represented in Fig. 5

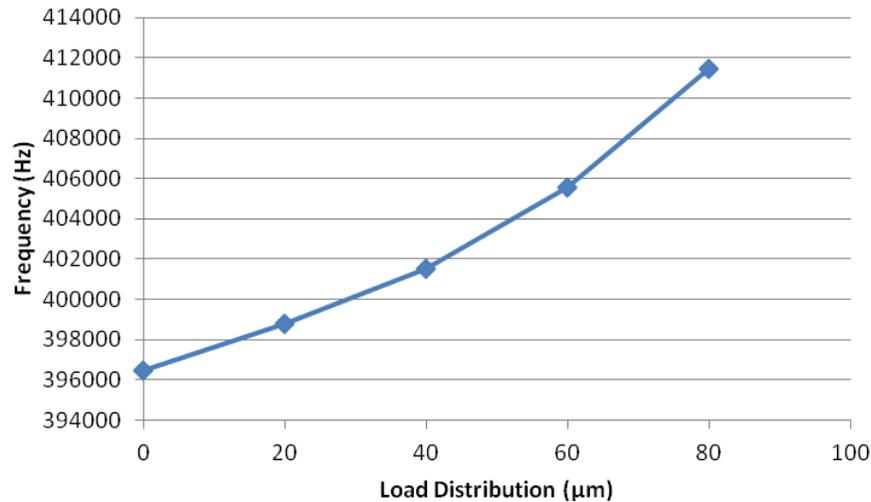


Fig. 5: Load Distribution across the beam

The sensitivity was found to be $4000/20 \times 10^{-6}$ which is a very efficient one and hence this sensor helps us to identify gas molecules even when the quantity is very as ppb.

3. CONCLUSIONS

This paper thus brings out the original methodology of measurement of the major polluting gas like carbon dioxide. The absorption of the chemical by a sensitive layer alters the overall mass of the sensing element that varies the resonant frequency i.e an increase in mass leads to a decrease in resonant frequency, this change in frequency gives the mass of CO₂ gas molecules present in the atmosphere. We also observe that when the change in mass is more the resonant frequency change is also more. Finally a micro-cantilever beams sensitivity is observed. This paper could be developed using the same principle to identify various gas molecules. The output could be an electrical signal if this cantilever could be a gate for the FGMOSFET. The obtained voltage could be compared and given to an alarm.

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