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MEMS BASED GAS SENSOR TO DETECT FOOD SPOILAGE

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Abstract

Airborne chemical sensors have gained wide importance in the daily necessities of life for the detection of hazardous and useful chemicals in food, health and pharmaceutical industry. A number of sensors have been designed for the sensing of gases such as array sensors, nanotubes and deflected cantilevers.

The MEMS based gas sensor is designed in a way that it detects the presence of the gases by chemically reacting with the polypyrrole coated substrate. The substrate is coated using spin coating technique. The uniform coating of 500µg pyrrole is performed. The reaction of this with ammonia gas released from spoilt food results in change in mass. This results in deflection of the sensor. Hence, this paper presents a detailed experimentation considering the salient features of polymer coated with pyrrole and its application as a chemical sensor emphasizing on the detection of food spoilage.

1. Introduction

Food poisoning is an ailment caused by eating or drinking food contaminated with harmful microorganisms such as bacteria, fungi etc. or by consuming food adulterated by chemicals. Ammonia is one among the most important gases released due to food spoilage with threshold limit of 25ppm and short term exposure limit of 35ppm [1]. Since, ammonia is one among the major released gases, it needs to detect. A sensor needs to be designed which can detect ammonia produced in small scale and operating at room temperature. Among the major conducting polymers, polypyrrole has an advantage due to its stability under atmospheric conditions as well as its ease of synthesizing by chemical and electrical techniques [2], [3].

1.1 Conductive Polymers

Plastic and polymers have better insulating properties. These are among the most used chemical substances in the daily life of every human being. Some of these polymers also have conducting properties which are known as conducting polymers. The nature, degree, amount of doping decides the chemical conductivity of a polymer [4].

1.2. Types of conducting polymers

The main chain of the conducting polymers contains cyclic structures, double bonds and a combination of the two bonds. Chemistry has given us so many conducting polymers namely, polypyrrole, polyaniline, polyacetylene, polyfluorine, polythiopene etc. along with their compounds inheriting the same conducting property [5]. Polypyrrole and polyaniline are found to be more responsive with biological and chemical reactants comparatively hence causing minimum amount of destruction to the environment [6]. In 2008, conducting polymer nano composites which have advanced and high ending properties was produced to remove the shortcomings of the conducting polymers [7].

1.3. Polypyrrole

Polypyrrole is found to be the boon in the field of conducting polymers. Its electrical conductivity, ease of synthesizing, compatibility with organic reactants was proved better than other polymers. Its conductivity is also compared to the conductivity of metals of around 1000 S/m [8]. Polypyrrole is used mostly in the sensor industry dealing with biochemistry because of the best compatibility with biological and chemical reactants [9].

1.4 Design and structure

Out of the three modules, rectangular shaped is the best amongst all the other cantilever designs as rectangular shaped cantilever beam will have maximum displacement for the applied load. Load (3.02148×10^{-12} N) is applied to the respective beams and the displacement is calculated. The displacement of the rectangular beam structure is $3.04*10^6$ µm, whereas the displacement of the T shaped cantilever beam is $2.36*10^6$ µm [10]. Hence for the MEMS based gas sensor the rectangular shape module is best suitable because of its maximum deflection, easy shape and less complex cantilever beam structure.

1.5 Block Diagram

Chem-sensors are the devices sensing the chemical reactant targeting it. The vapour analyte reacts by a lock and key mechanism.

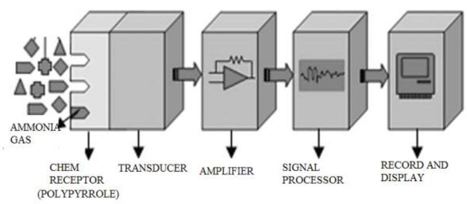


Figure 1. Block diagram with chem-sensor

2. Solution Methodology

2.1. Micro cantilever beam design

It is a mechanical cuboidal solid structure constraint at one end and free from the other which shows deflection when acted upon by stress [11]. The cantilever beam acts as a sensor which detects the cantilever bending and the changes in vibrational frequency. The cantilever beam is coated with a layer of sensing material pyrrole (Azole, Divinylenimine) C4H5N M.W.67.09 over which vapour analyte ammonia reacts by a lock key mechanism. There are different cantilever designs such as pi, T, E, Rectangular and triangular cantilever beam. The different beam structures is analysed for the same force applied to detect food spoilage [12], [13], [14]. Food poisoning caused by chemicals due to the production of harmful chemicals by the microorganisms in the food, consumption of the same can cause illness [15].This problem demands the design of sensors with such structures to eradicate the cause of this illness.

Table 1. Dimension of cantilever

length	breadth	Thickness
220µm	50µm	5µm

2.2. Chemical module design

The following chemicals were involved in the experiment: polypyrrole, ammonium hydroxide, ammonium chloride and calcium hydroxide.

3. Experimental Analysis

The chemical reaction between ammonium hydroxide and pyrrole in 1:1 ratio was carried out in a conical flask which was constantly being heated. The polymerization was carried out. There was a thin film formed in the beaker. This experiment proved that when polypyrrole reacts with ammonia there is a formation of layer which in microscopic level would result in deflections.

In the second experimental analysis, films of polypyrrole were deposited using spin coating method on a precleaned glass substrate with acetone (size 220 µm $\times$ 50 µm). The glass weight was measured using Sartorius - CP64 - 64g capacity - 0.1mg readability - CP Series Analytical Balances. After the weighing Spin coating was performed using the SpinNXG-P1A equipment with Teflon coated working chamber of 8 inches diameter and a 15 pre-set editable programs. The speed in which the coater worked was 5000rpm. The coating was done 5 times; each time with 50µl of pyrrole solution with resulted in a deposition of 0.5mg of pyrrole on the substrate.

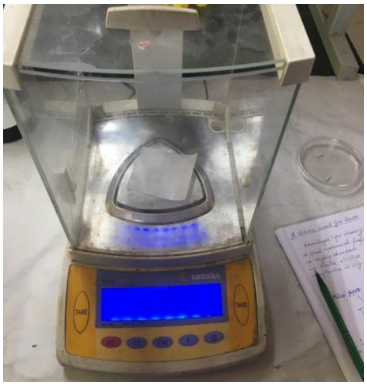


Figure 2. Weighing Machine

The final experiment was performed by reacting the substrate with ammonia gas. The ammonia gas was produced reacting ammonium chloride (NH_4Cl) and calcium hydroxide [Ca (OH) $_2$] in 2:1 ratio. A solution was made with the chemicals and water. The solution of the two chemicals was gently heated; this resulted in production of ammonia. The reacted sample was weighed.

4. Calculation

Weight of substrate= 0.1987g

Weight of substrate after pyrrole coating=0.1992g

Weight of pyrrole coated=0.5mg

Spin coater:-

Speed-5000rpm

Coating performed-5 times (each time a coating of 50µl)

Weight of substrate after reaction with ammonia gas=0.1993g

Dimension of substrate (A) = (220*50) μm^2

Force calculation:- F= m*g (m is the mass of ammonia deposited)

=0.0001*9.8

=0.00098

P=F/A

F= (0.00098) / (220*50*10^{-3}) Pa

=0.089Pa

5. Graphical Data of Spin Coater

The spin coater machine was rotated with a speed of 5000rpm and according to the graph referred below; the thickness of the pyrrole coated over the substrate was around 200nm.

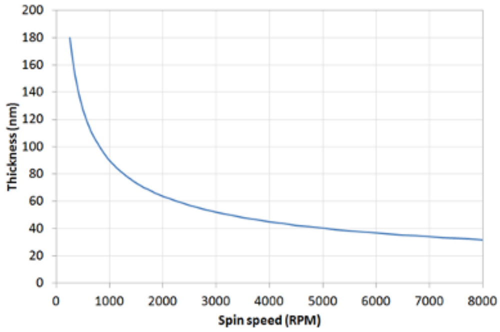
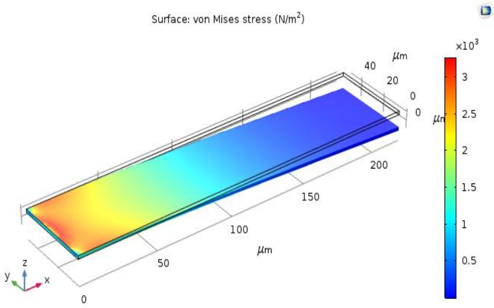


Figure 3. Thickness vs. speed graph

6. Simulation

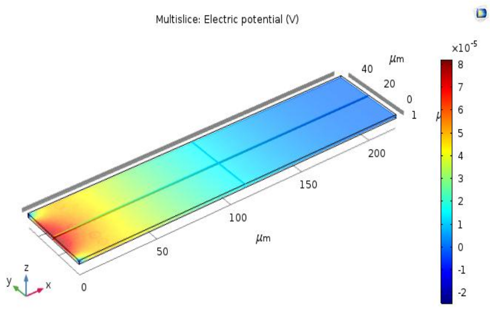
6.1. Deflection due to stress

The figure below shows the mass loading on the cantilever beam. The mass accumulated on the surface of the substrate due to redox reaction of sensing polyprrole with ammonia vapour is examined and this mass accumulation is responsible for deflection of the cantilever beam.



6.2. Read out mechanism

As a read out mechanism, we need to convert the displacement caused by deflection into a unit which can be recorded, for this; a piezoelectric mechanism has been used to record the voltage caused by mass accumulation.



There were various analyses that were performed with respect to its effect on the output voltage. The parameters that were considered were stress, strain, pressure and displacement. The following results were obtained.

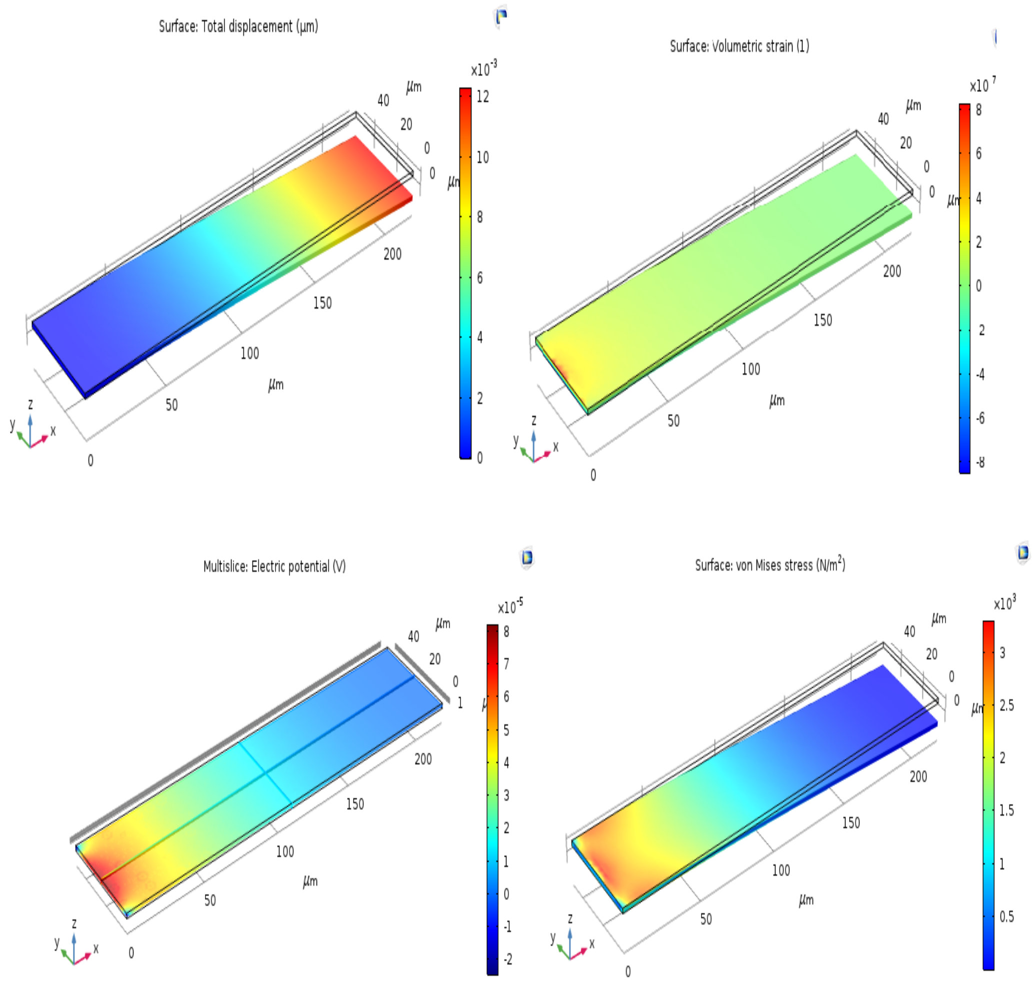
7. Simulation Results

By taking various parameters which affect the cantilever, the simulations were performed. The effect of each parameter on the read out mechanism (i.e. voltage) was studied using respective graphs by varying the values.

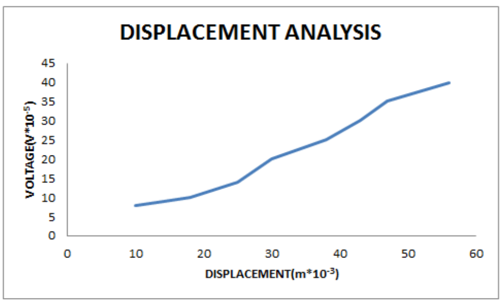
Table 2 shows the different values obtained during the simulation.

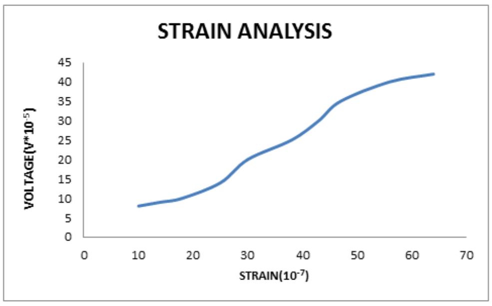
Table 2. Values of the considered parameters

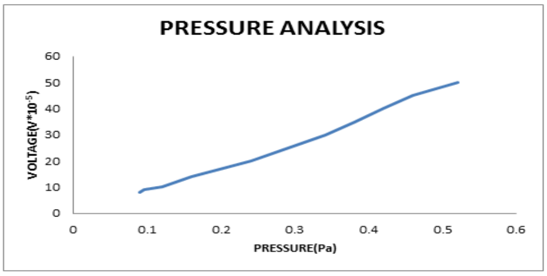
Pressure (Pa)	Stress (N/m^2*10^3)	Strain (10^{-7})	Displacement ($m*10^{-3}$)	Voltage ($V*10^{-5}$)
0.089	3	14	12	8
0.096	3.5	19	16	9
0.12	4	25	22	10
0.16	5	31	25	14
0.24	8	36	30	20
0.29	10	41	38	25
0.34	12	47	43	30
0.38	14	52	47	35
0.42	17	64	56	40

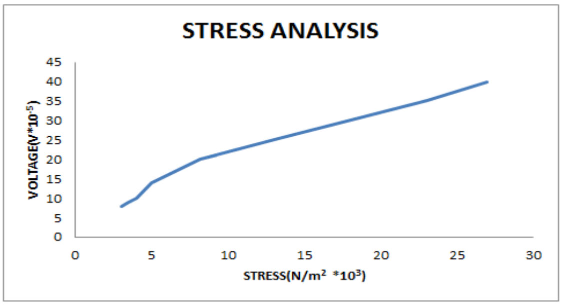


From the obtained values, graphs were plotted to see the behaviour of the sensor under different conditions.









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