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MEMS Piezoresitive cantilever mass sensor response for detection of volatile organic compounds using Omnicant experimental platform

K.Durga Aparna, D.V.Rama Koti Reddy, B.Rajesh Kumar

Abstract: ***MEMS piezoresitive cantilever is a system that is utilized to identify VOC molecules like acetone, ethanol, isopropyl and ethyl acetate. These molecules have molecular weights ranging from 46.07gms/mole to 88.1gms/mole. These molecules can be identified due to the deflection changes of the cantilever when the change in the mass occurs due to the deposition of molecules on the cantilever. Thus in this paper the responses from the piezoresistive micro cantilever with different analytes using OMNICANT were obtained.***

Keywords **:** ***Piezoresitive cantilever, OMNICANT, VOC.***

I. INTRODUCTION

Volatile organic compounds (VOC's) are one of the common sources of indoor air pollution. The sources of VOC's in the entire environment includes different products like paints, varsnishes cosmetics, etc; These products emit an unpleasant smell which contains harmful compounds like chloride, benzene and acetone which causes different health hazards to human beings like resipiratory problems, headaches, nausea. Due to the emission of VOC compounds from industrial environment the volatile organic compounds have the major possibility to cause cancer. The VOC's which are now available in todays market are mainly focusing on the contents available in VOC's mixtures and detection of concentration to gain portability.

II. PIEZORESISTIVE MEMS CANTILEVER

The piezoresistive MEMS cantilever which is attached on a PC board and wire bonded is shown in fig.1.

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* Correspondence Author
K.Durga Aparna*, DST Women Scientist ,Research Scholar, Departmnet of Instrument Technology, Andhra University Visakhapatnam.
Prof.D.V.Rama Koti Reddy Departmnet of Instrument Technology, Andhra University Visakhapatnam.
Dr.B.Rajesh kumar, Associate Professor, Department of EIE, Gitam University Visakhapatnam

The cantilever resistance detection range is from 27kOhma to 90kOhms. The physical dimensions of the cantilever are (200µm×80µm×0.6µm). The cantilever has three layers
Bottom layer Silicon Dioxide (0.40µm)
Middle layer Poly Silicon (0.15µm)
Top Layer Oxide (0.05µm)

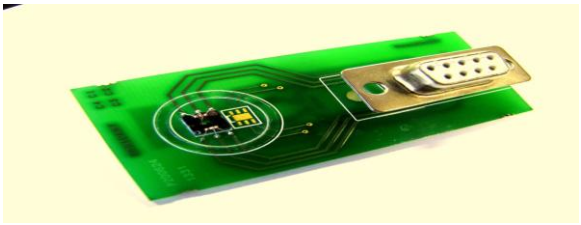

Fig. 1.

The top and bottom layers are the sensing surfaces on which the analytes are deposited to create deflection in the cantilever which produce stress and the middle layer is the piezoresistor for sensing the stress when analyte comes in contact with the cantilever.

III. OMNICANT WORKING

Omni cant is a piezoresistive MEMS and NEMS Cantilever based experimentation platform for research and education in Nano technology. It is basically used to study the chemical interaction of Volatile Organic Compounds and gases with coated reagent, analyses chemical kinetics, reactivity and other characteristics under different environmental conditions. Omnicant consists of an Analyte Chamber, a Detection Chamber, Mass Flow Controllers along with multi-channel real-time graphical display, data logging and PC software. The basic set up is shown in fig.2.

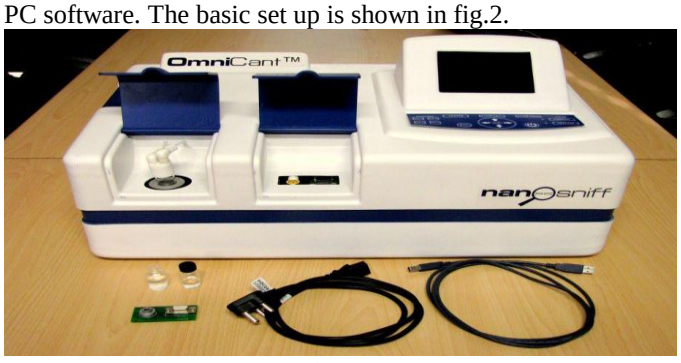

Fig 2.

A Vial in the Analyte Chamber houses the target compound to be detected (as a liquid) which is shown in fig.3. This target solution is heated to generate it's vapours.

Fig.3.

There is a Detection Chamber where the MEMS Cantilever is housed which is shown in fig.4.

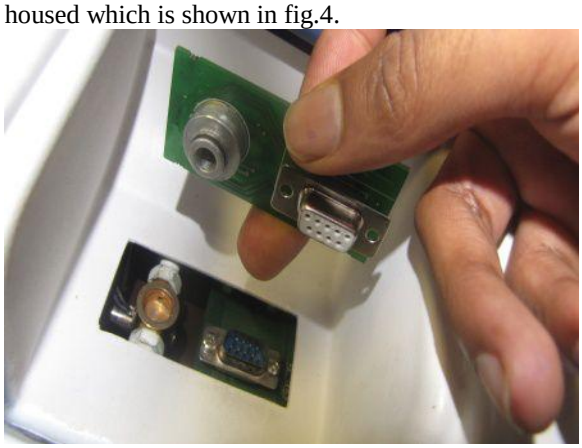

Fig.4.

The surface of the Cantilever is functionalized with a compound having affinity for the target compound. The vapours of the target compound are carried to the Detection Chamber using MassFlow Controllers and a Carrier Gas (Nitrogen– as it is inert). The nitrogen cylinder has primary and secondary gauges which is shown in the fig.5. The secondary pressure should not be more than 2 bar and the primary guage reading can be half of the total range.

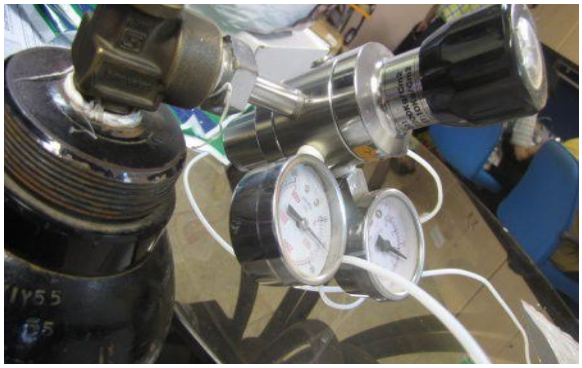

Fig.5.

Here, the MEMS Cantilever is exposed to the target vapours Due to the affinity between the target vapours and surface functionalized cantilever, physical adsorption/chemical binding takes place on the surface of the cantilever. This causes a change in surface stress leading to a deflection of the Cantilever. This nanomechanical deflection leads to a strain in embedded piezoresistor, which in turn causes a change in the resistance of the Cantilever. Once the flow of target vapours is stopped, the cantilever goes back to its original state and it's resistance returns to the original value.

This interaction between the Cantilever and the target vapours is seen real-time on the display as a plot of Resistance v/s Time which is show in fig.6.

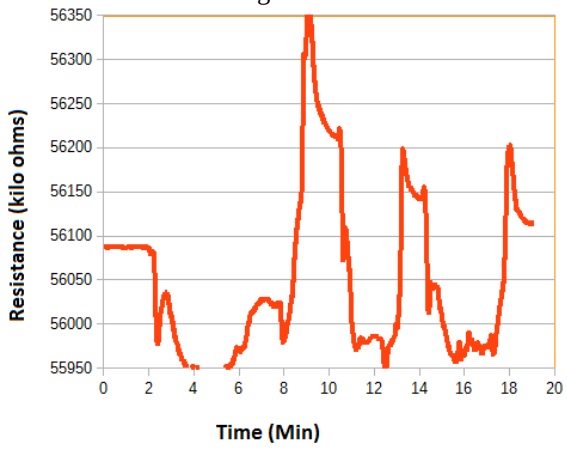

Fig.

IV. EXPERIMENTAL RESULTS

1. The Acetone (VOC) interaction with 4-MBA coated piezoresistive microcantilever : The fig7. shows the 4-MBA SAM preparation on gold.

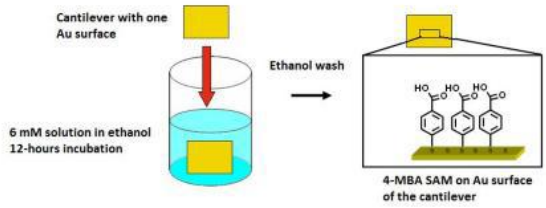

Fig. 7.

The concentration of the analyte can be reduced using the suitable diluent. The dilutions can be prepared using 10ml volumetric flasks.

Table.1. Proposed analyte dilution V/V at 22ºC

S.No.	Acetone (%)	Toulene (%)
1	100(8.00ml)	00(0.00ml)
2	80(6.40ml)	20(1.60ml)
3	60(4.80ml)	40(3.20ml)
4	40(3.20ml)	60(4.80ml)
5	20(1.60ml)	80(6.40ml)
6	10(0.80ml)	90(7.20ml)
7	5(0.40ml)	95(7.60ml)

Table.2 Proposed variations in flow rate of gas and variations in temperature of analyte.

S.No.	Flow rate (in sscm)	Temperature
1	10	Room temperature
2	15	35
3	20	40
4	25	45
5	30	50

2. Mechanism of the cantilevers with acetone analyte: Since Acetone can be vapourised at room temperature and chemically inactive to polar molecules this will interact via Vander Walls with carboxylic acid. The intermolecular interaction mechanism of cantilever with acetone is shown in Figure 8.

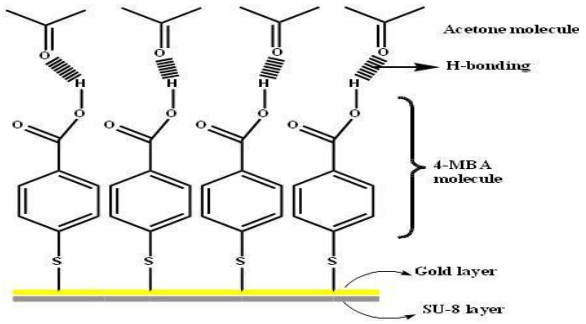

Fig.8.

The response of Acetone curve upon exposures to the 4-MBA coated device is shown in figure 9. It can be observed from the study that 4-MBA gives good response with acetone .

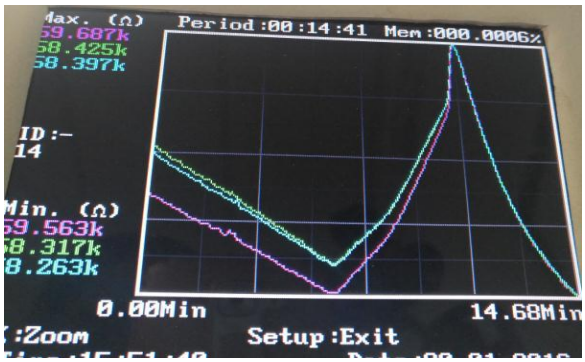

Fig.9.

3. Deflection Mechanism of cantilevers with Ethanol testing with poly vinyl pyrrolidone (PVP):

Ethanol also called as Ethyl alcohol is a chemical compound with a slight characterstick odour. The chemical adsorption may take place between the hydroxyl hydrogen atom of alcohol and nitrogen atom in the pyrrolidone ring. The amine group in the ring is capable of serving as an H-bond acceptor whereas H-bond donor in these cases is the ethanol hydrogen (-OH).

The Ethanol response curve upon exposures to PVP coated device as shown in figure 10.

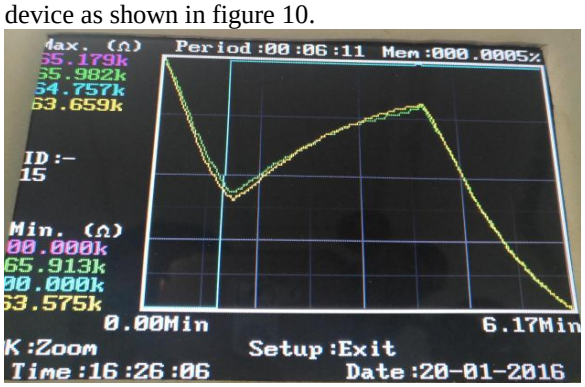

Fig.10.

V.Testing of PVP coating

Samples were characterized by resistance measurements made at the optimum temperature (for sensing) of 65ºC for different analyte concentrations. Variation in sensitivity at 55ºC to TNT gas with PVP coated MEMS cantilever, at different gas concentrations is shown in Figure 11.

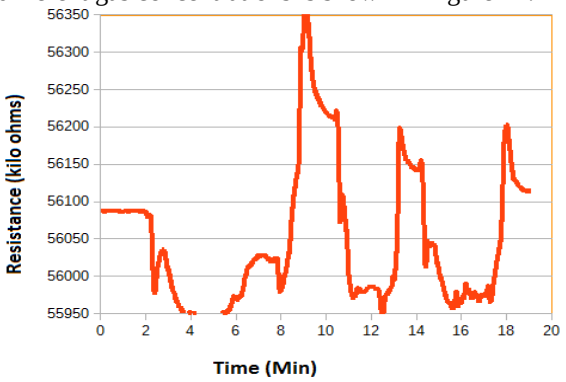

Fig.11

An increase in sensitivity was observed with increase in concentration when the concentration was in the range 50 SCCM to 55 SCCM. A maximum sensitivity of 58% for acetone concentration of 55SCCM was observed. The variation in sensitivity of the cantilever for different analyte concentrations is as shown in Figure 12.

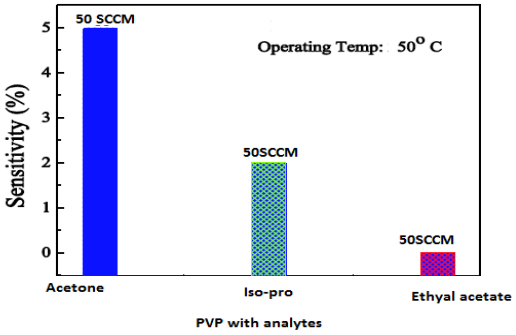

Fig.12

VI. Sensitivity characteristics of PVP coating

The measurements were made to evaluate the cantilever response within a range of 60 SCCM to 65 SCCM of analyte mixed. The test was carried out by introducing Omnicant equipment for 22 minutes following nitrogen gas for 10 minutes. The sensitivity characteristics are as shown in figure 13. Sensitivity of the cantilever response is measured as shown in equation.

$$\text{Senstivity} = R_g\text{-}R_a/R_a$$

Where Rg and Ra are resistances in the analyte gas and air respectively.

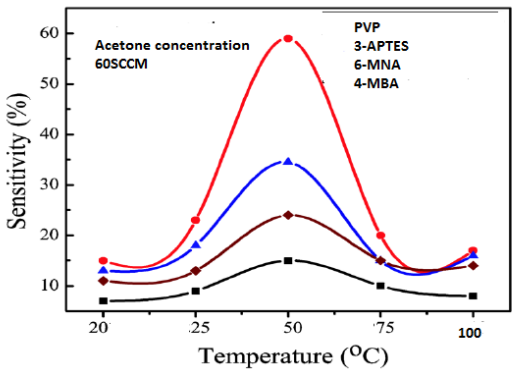

Fig.13

VII. CONCLUSION

The responses of piezoresistive cantilevers with two analytes under resistance versus time is presented in this paper. Finally the PVP coated cantilever has more sesntivity based on a variation in physical and chemical properties of the sensing material under gas pressure. This cantilever can be used as a microsensor as a part of the total analytical system (TAS) designed for detecting the Pb(II) level in drinking water.

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AUTHORS PROFILE

K.Durga Aparna DST Women Scientist ,Research Scholar, Departmnet of Instrument Technology, Andhra University Visakhapatnam.

Prof.D.V.Rama Koti Reddy Departmnet of Instrument Technology, Andhra University Visakhapatnam.

Dr.B.Rajesh kumar, Associate Professor, Department of EIE, Gitam University Visakhapatnam

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