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DETECTION OF VOLATILE ORGANIC COMPOUNDS USING MEMS BASED MICROCANTILEVER: A REVIEW

CH. Jaya Prakash[1] and N. Siddaiah[2]
[1]Department of ECE, Koneru Lakshmaiah Education Foundation, Vaddeswaram, Guntur District of Andhra Pradesh, India
[1]Department of ECE, Sir C R Reddy College of Engineering, Eluru, India
[2]Department of ECE, Koneru Lakshmaiah Education Foundation, Vaddeswaram, Guntur District of Andhra Pradesh, India
E-Mail: jp.chennoju@gmail.com

ABSTRACT

This survey presents a literature review of metal oxide-based volatile organic compounds (VOC) sensor detection and cantilever based sensors for the checking and recognition of unpredictable natural mixes. The study contains data gave by various partners and writing concentrated on recognition of VOC gases like n-octane, toluene & n-butanone, Ethanol, Acetone, Pentaerythritol, tetra nitrate& 2,4,6-Trinitrotoluene with sensitivities, the limit of detection was presented. Parameters like resonant frequencies, quality factor and deflection properties of length versus width are measured for different MEMS cantilever structures.

Keywords: benzene, toluene, butane, cantilever, MEMS, volatile organic compounds.

INTRODUCTION

Due to chronic exposure hazardous compounds like Volatile organic compounds (VOCs) may cause damage to Human and living beings [1]. More number of techniques are available for VOC. High goal sub-atomic detachment approaches, for example, mass spectrometry and gas chromatography are all around described and offer high affectability, however are hard to execute in versatile, continuous screens, while approaches, for example, MOS resistive sensor are promising, yet at the same time requests greater affectability

Cantilevers can go about as concoction of organic sensors as soon as covered by a detecting coat or receptor atoms, the mass and firmness of the cantilever are changed by Target atoms pre-occupied by the functionalized plane. The progressions such produced causes a move on performance factor and Eigen recurrence that is distinguished by strain measures and converts to a sign corresponding to the objective focus [2].

MEMS gadgets are generally utilized in the territory of sensors, for e.g. pressure sensors, optical sensors, mouthpieces, actuators, and so forth. Cantilevers are generally designed utilizing mass micromachining, surface micromachining, or a mix of both. In each micromachining cycle, a strong structure is delivered from the wafer to make an unattached bar, moored toward one side. Contingent upon the application three stomach shapes, round, square and rectangular are utilized. The decision of stomach shape depends basically on the manufacturing cycle utilized for acknowledging it. Moreover, it relies on a few different factors, for example, the applications and appropriation of the necessary pressure field. As a rule, square and rectangular shapes are favoured because of the simplicity of creation. In mass micromachining, the cantilever is delivered from the greater part of the wafer's substrate. In surface micromachining, the cantilever is delivered from a surface layer. Both micromachining measures take into consideration the manufacture of a solitary cantilever or a variety of cantilevers. These cycles likewise take into consideration the creation and reconciliation of the electronic hardware and different MEMS parts required to interface with the cantilevers.

MEMS-based cantilever sensor for VOC discovery is being developed. The VOC mixes comprise of aromatics, for example, xylene, toluene, benzene and ethylbenzene (BTEX) and aldehydes, for example, formaldehyde and acetaldehyde.

MOX Sensors for VOC

In industrial sensors, the property extremely estimated in sensors made up of metal oxide is the resistance. Oxide made with SnO_2 is mainly utilized because is more reactive and solid changes in obstruction. In general, the model is acknowledged, that tin oxide structure grains and the conductivity is ruled by the limit of grains. In general oxygen in the surrounding air, if there is an oxidizing gas nearby, the gas atoms respond with oxide of tin catching electrons at a superficial level, creating a positive charge space at the boundary to conduct.

MOx sensors moreover respond to inorganic gases, which quantify less number of centralizations of VOCs where gases like CO or SnO_2, NO are in like manner exist in high obsessions. Thus, when there is use of MOx sensors, long stretch security information, cross-affectability to vaporous interfere blends, sogginess affectability is likely critical to address the response of a sensor. MOx sensors are judicious while distinguishing VOCs a small number of examinations indicate the major responsive oxides for VOCs fuse the following after sorts: WO_3, SnO_2, and ZnO [3,4,5].

In 2009, Ke *et al.* [6], a sensor of benzene gas based on MEMS was developed, comprising a substrate made of quartz, meagre coat WO3 detecting layer, a coordinated Pt small scale warmer along through Pt inter digitized cathodes (IDEs). The warmed WO_3 is oxidised by benzene, directs electrical resistance between the IDEs.

The ideal working temperature of 300°C, the sensor had a serious extent of affectability, a recognition breaking point of 0.2 ppm and a quick reactivity of (35s).

Here Table-1 gives survey report on different target gases presented by authors for detection of VOC.

Table-1.

Ref.	Focused VOC gas	Layer concentration	Limit of detection in ppm	Response Time
[7]	C_7H_8, C_8H_{10}, C_6H_6	Au-SnO_2MO_Xx + pre-concentrator	1-3	-
[8]	C_6H_6	TiO_2	10	35s
[9]	Aromatics Hydrocarbons	Pd-WO_3 at 400 OC	Toluene: 0.01–1.0	--
[10]	C_6H_6	WO_3	0.2	20s
[11]	Methanol, Ethanol, Acetone and Formaldehyde (VOCs)	SnO_2–TiO_2 doped with Ag	For ethanol about 10	20 s
[12]	Methanol, Ethanol,Formaldehyde, and acetone (VOCs)	SnO_2doped with TiO_2	10	10-20s

Electronic Noses and Sensors Arrays for Detection of VOC

Rock *et al.* [13] and Wilson and baietto [14] introduced monetarily accessible e-nose and their conceivable use. These devices are especially fascinating in favour of scent recognition. Lee *et al.,* 2002 [15] introduced a variety of ten distinct gas MOs-sensors (SnO_2) incorporated in order to distinguish different sorts along with amounts of VOCs, for example, benzene, toluene, ethyl liquor, methyl liquor. The silk printing technique on the alumina substrate is used to manufacture the sensor. The examination indicated an elevated and wide affectability and regenerate ability to low down focuses regarding the nano-sized detecting materials. The creator likewise executed detecting signs that exhibit a fake neural system that has a blunder back-spread knowledge of calculation. The reenactment along with test outcome indicated that the gadget utilizing neural system had the option to perceive and measure different sorts of VOCs.

Srivastava [16] demonstrated the chance of utilizing a variety of SnO_2doped gas sensors (Pt, Pd and Au) for the location of VOCs. Utilizing a three-layer feed-forward neural system classifier having better precision dependent mean and change of the gas-sensor mix, the creator indicates e-nose had the option to effectively recognize seven VOCs still utilizing good information. Be that as it may, here be no further endeavour to measure distinctive VOCs.

Penza *et al.* [17] detailed explanation about nanolayer and nanocomposite sensors have enhanced affectability in presence of natural gases. These are made up of multi-sensor gadget utilizing Langmuir *etal.* saved multilayers of Monolayer CNT (Carbon Nano Tube) on SAW (Surface Acoustic Waves), quartz-microbalance, and OFC (Optical Fiber Cable) of standard silica. This multi-sensor layer presented to six VOC perfumes. Insight of trial results, utilization of multi-sensors dependent on CNTs and example acknowledgement methods was proposed for the effective assessment of Volatile Organic Compounds.

Han *et al*. [18] projected to utilize a variety of nano-sized sensors to distinguish a blend of natural gases. The nano-structure exhibit depends on meagre film gathers thiolate of alkenes-monolayer-topped gold nano-particles (2-nano meter) shaped by molecule interceded together utilizing arbiters of different chain lengths and useful gatherings. Every cluster tried for C_6H_6,$C_6H_5(CH_3)$, $C_6H_5CH_3$, $C_6H_5NO_2$, and $C_7H_7NO_2$estimations indicate straight reactions. Now the reaction is examined with counterfeit neural systems through standard segment investigation method. Be that as it may, in this investigation, the tried grouping of natural mixes was between a few ppm to a large number of ppm, a long way from the focused on encompassing space function.

Wolfrum *et al.* [19] introduced a sensor in the year 2006 which exhibits, depending on 14 MO_XFigaro-sensors with force provides voltage ranging from 1-5 V in addition to a high temperature and a stickiness sensor. later than research facility adjustment, the Partial Least Squares procedure utilized for information management and evaluation up to 10 VOCs ranging from 10 to 300 ppb adjusted on behalf of internal air checking.

De Vito *et al*. [20] offered an e-nose throughlow-cost MO_X sensors in 2008, fabricated by Pirelli-Labs (IT). This paper proposed a new approach based on field calibration to avoid the poor selectivity and immovability of MO_X with calibration to calculate the concentration ofC_6H_6. The authorconduct a reliable examination on sensor combination for measurement by utilizing customary air contamination observing station as reference information. The results were assessed employing error-predication and characterization over the 13-month campaign. The authors indicate a neural alignment with just few estimation days had the alternative to restrict the outright expectation mistake for over a half year.

MEMS Design for VOC Detections

M Maute *et al.* [21] introduced the frequency of resonance changes of polymer-covered cantilevers because of gas ingestion is demonstrated as it is a promising discovery gas component. Masterminded SiNx cantilevers subject to micromachined Si wafers and used $(C_2H_6OSi)_n$PDMS as polymeric model covering as illustrated Figure-1. This estimates the resonance recurrence reaction of cantilevers end-covered with polymer on presentation to various fume convergences of n-octane, toluene, and n-butanol and decided high sensitivities as for cantilevers without polymer covering. By utilizing the main higher eigenmode, initiate by this setup sensitivities up to -0.0988 Hz/ppm for little groupings of n-octane, 0.0409 Hz/ppm for little centralizations of toluene and - 0.0033Hz/ppm for little convergences of n-butanol. From this, it is clear how the affectability of the concoction sensor being improved by irregular polymer mass

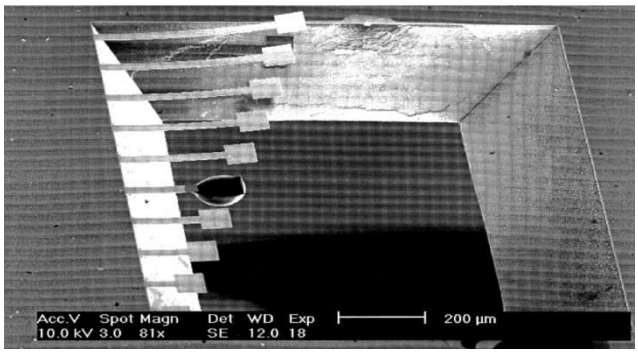

Figure-1. SEM picture of a variety of distinctively estimated cantilevers. The 240-mm long cantilever was covered with PDMS at the square-moulded end.

The vast majority of the distribution covers the VOCs estimation sensors. Amongst the fundamental ones, Ho *et al.* [22], in 2001, introduced an audit regarding sensors which equip distinguishing and checking VOC for long haul atmosphere contamination observing.

A. Hajjam *et al.* [23] Polymer covered with piezoresistive micromechanical complete silicon nano-levels is used for identification and focus estimation of unpredictable natural mixes within the gas stage. Polyglycolic $(C_2H_2O_2)_n$ corrosive, the principle polymer element of the Shipley-1813photoresist, was utilized because of the soft covering layer. Investigations have demonstrated thickness of polymer decides feasible affectability towards gas particles and resonator width of the stored gas fume outside the sensor decided by the adjustment within the resonant recurrence of the resonator. The electrical associations and parts required for detachment of the AC incitation be due the DC predisposition flow required for activity of the resonator have likewise appeared in Figure-2a. Figure-2b shows the in-plane extensional resounding method of an I-formed resonator.The watched greatest recurrence move of 3600 ppm (55 kHz) was accomplished while an identical layer of photoresist utilized for designing of the gadgets, was utilized because the permeable covering the resonator layer. This recurrence move is proportionate to a retained natural layer of 60nm thick in fluid structure. Least Level of Detection quantifiable is 4.8ppm. By utilizing the last covering technique, the reaction times have profoundly diminished, from 4min to 40 seconds. In light of the estimation results, least noticeable centralization of toluene within the gas stage for such gadgets is within the scope of a few ppm.

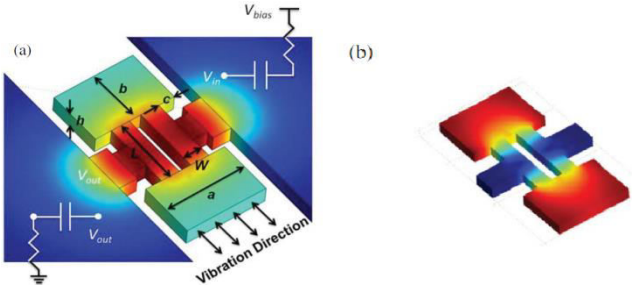

Figure-2. (a) Schematic perspective on a thermally impelled I-formed resonator indicating the subjective conveyance of temperature change sufficiency. The electrical associations for the activity of the resonator are additionally appeared (b) COMSOL Eigen recurrence investigation results, demonstrating the in-plane Eigenmode shape for a thermally incited I-molded resonator. Red and blue hues show areas with the biggest and little variation in amplitudes separately.

Shiraishi *et al.*[24] in this paper the Polycarbonate-based double cantilever sensors contain a cantilever, it covered with PBD, cantilever with PVDF piezoelectric films utilizing holding, laser design and polymer covering procedures as demonstrated Figure-3. Here we analyzed the adjustment insight of VOC fume by putting in the PC-based double cantilever sensor assessment framework outfitted with a weakening stream framework, temperature-controlled chamber, wavering circuit, and recurrence counter. The frequency of resonance along with recurrence of both the cantilever and PBD-covered cantilever moved fundamentally descending through the toluene, octane and ethanol presentation.The identification affectability of the Polycarbonate cantilever for toluene, octane and ethanol were 9mHz/ppm, 9mHz/ppm and 2mHz/ppm, separately. The placement affectability of the PBD-covered Polycarbonate cantilever for toluene, octane and ethanol were 47mHz/ppm, 40mHz/ppm and 10mHz/ppm, individually.

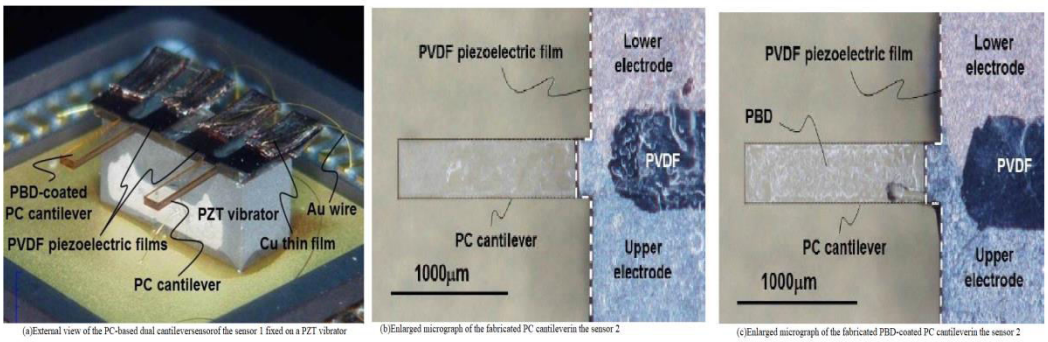

Figure-3. Photos of the manufactured PC-based double cantilever sensors.

M. P. Abreu *et al*. [25] A framework dependent on a variety of eight smaller-scale cantilevers for unstable natural mixes (VOC) location as appeared in Figure-4. Micromechanical sensors exhibit of silicon and jewel cantilevers coupled to a help chip that incorporates a couple of strain measures and three metallic cushions to permit outside electric contact are sharpened for the discovery of analytes utilizing polymer coatings.The sensors designed are not permanent and modifications are made for a new application. Recognitions of VOCs are shown in this Polymer covered silicon miniaturized scale cantilever is manufactured and tried for the location of Pentaerythritol tetranitrate and 2,4,6-trinitrotoluene. This work shows that keeping diverse slender movies of polymers on the surfaces of miniaturized scale cantilevers unequivocally impacts affectability and selectivity toward analytes that present various potential methods of sub-atomic acknowledgement were finished.

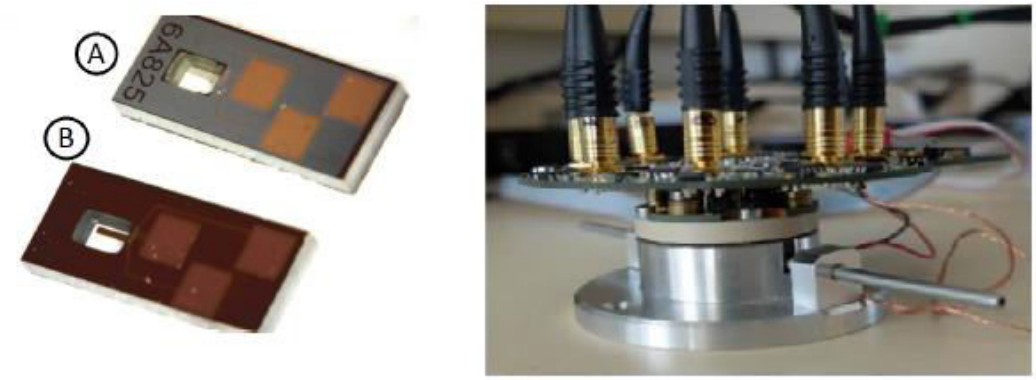

Figure-4. Optical magnifying instrument picture of microfabricated (A) and silicon (B) cantilever and Gas estimation cell associated with simple handling board

S. Sri Surya Srikanth *et al*. [26] this paper presents the structure of the VOC sensor utilizing MEMS. A cantilever of rectangle shape bar with measurements 225µmx80µmx2µm is planned and reenacted. Miniaturized cantilever based senor is used for physical substance and bio-molecule detection. The Figure-5 indicates Electronic instrument, which contains minimum 4-chambers for the analyte, location, mass stream regulators alongside multichannel constant graphical showcase and logging, memory frameworks.In a key boundary, avoidance property was concentrated logically just as with programming with Intellisuite. The Microcantilever was tried tentatively on omnicant tool with acetone as an analyte. Later the designed cantilever was tested with omnicant and observe the change in resistance. It is seen that the trial results by -10% from the reproduced results. As a consequence in this paper articulate that projected cantilever is utilized for VOC Sensing with large affectability.

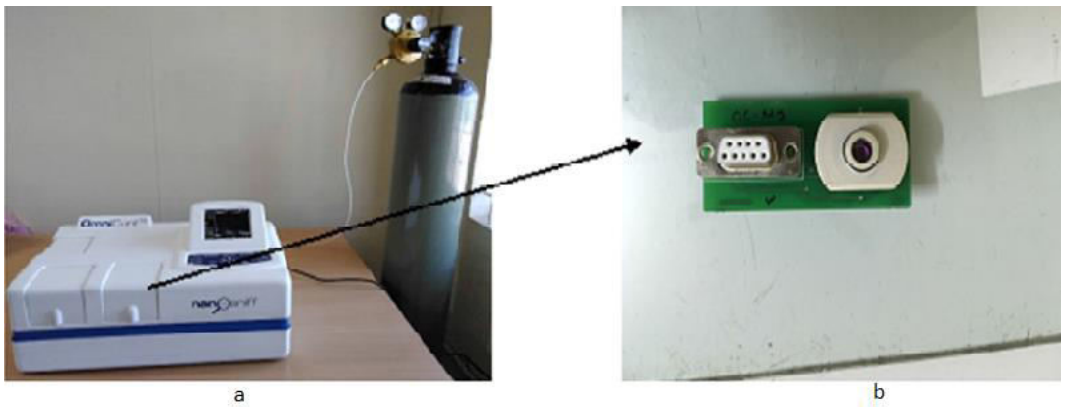

Figure-5. (a) Experimental setup with omnicant (b) designed Cantilever module used in Omnicant.

N. Shiraishi *et al*. [27] polymethyl methacrylate $(C_5O_2H_8)_n$ and cantilevers made-up with polycarbonate (PC) were designed by hot emblazoning, holding, and cleaning strategies. The photo in Figure-6a shows the entire PMMA cantilever chip The PC cantilever chip had comparable measurements. Figures 6b & 6c shows an enlarged version of the handled polymethyl methacrylate cantilever (PMMA3) and Polycarbonate cantilever (PC3) designed at the centre of the cantilever. The dimensions and mode of the Eigen frequencies and quality factor of the above two types of cantilevers under air pressure were examined to acquire principal information for polymer-based VOC sensors.The deliberate Eigen frequencies related finely to hypothetical undamped Eigen recurrence of a flexible-vibrating cantilever. The deliberate quality variables shifted from Ten to more than Hundred, contingent upon the vibration mode. A higher model would, in general, show a greater factor, and the modulus E' and dissipation E'' were estimated by using a mass PMMA plate and a mass PC plate (20mm×5mm×0.2mm).

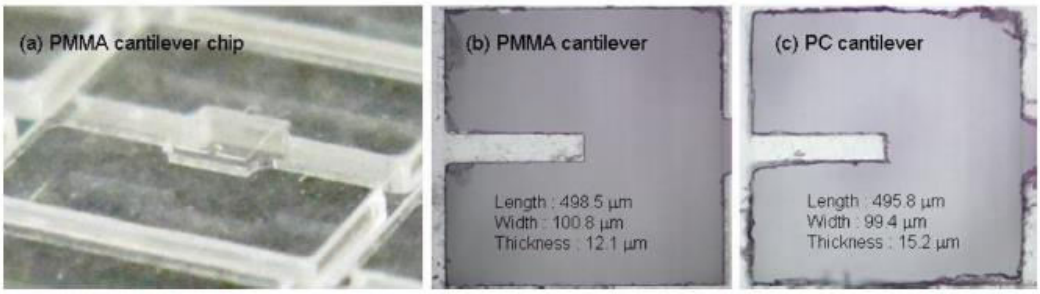

Figure-6. (a) Photograph of the completed PMMA cantilever chip; (b) micrograph of the PMMA cantilever; (c) PC cantilever.

Here Table-2 presents MEMS design for Different VOC detection presented by authors.

Table-2.

Ref.	Target gas	Design (shape used)	Sensitive layer	LOD in ppm (limit ofdetection)	Sensitivity, Hz/ppm	Parameters measured
21	n-octane, toluene & n-butanole	The 240-um long cantilever was covered with PDMS at the square-formed end.	polymer PDMS	--	−0.0988, -0.0409 & -0.0033	Resonance frequency
23	Toluene	I-shaped resonator	Polyglycolic acid	4.8	max frequency a shift of 3600 ppm (55 kHz)	Thickness &resonators at different bias currents
24	Toluene, Octane & Ethanol	Sensor-based on Double- cantilever detects VOC gases: the PC cantilever	PVDF piezoelectric films	192, 186 and 777	0.009, 0.009 and 0.002	Resonant frequency
		PBD-coated PC cantilever	PVDF piezoelectric films	55, 64 and 252	0.047, 0.040 and 0.010	
25	Pentaerythritol Tetranitrate & 2,4,6-Trinitrotoluene	Silicon micro-cantilver	Polyepichlorohydrin (PECH), Polyethylmethylmethacrylate (PEMMA), Polyisobutylene (PIB) and Polymethylmethacrylate (PMMA)	--	--	Detection of 1µg of PETN & 200ng TNT resulting in 5Hz offrequency shift
		Diamond-micro-cantilever				
26	Acetone	Rectangular cantilever beam 225µmX80µmX2µm	(1-100) ml/min N_2 gas carrier	-	-	Deflection property with length vs width is varied by 5% experimentally & theoretically

Katta *et al.* [28] the sensitivity and selectivity are key constraints for sensing the real-time environment applications along with significant response time and good dynamic range. In this, a T-shaped NEMS Cantilever structure is planned and re-enacted utilizing COMSOL FEM analysis tool. The effect of length and load on deflection sensitivity and the impact of thickness on the resonant frequency of the cantilever beam for different materials have been analyzed. From the experimental results, the deflection sensitivity of the cantilever beam made up with CNT material posses $9.85\,X10^{-8}$ meters under maximum stress of$6.71\,X10^{-9}$ N/m^2 for the length 300 nm and minimum for Silicon dioxide as $0.3x10^{-9}$m under maximum stress of $6.49x10^{-9}$ N/m2 at the same length. Similarly, deflection sensitivity under variable load analysis the CNT material exhibits $6.72x10^{-10}$ m at 100 µN force as load and Polysilicon exhibits poor deflection for the same load as $1.62x10^{-10}$ m. The simulation results of the resonant frequency of a cantilever beam for CNT material are 18 MHz at 10 nm and 75 MHz at 50 nm thickness respectively. From the critical analysis, it is identified that deflection sensitivity and the resonant frequency of Si3N4 and SiO2 materials are in close approximation and Si3N4 exhibits good response compared to remaining materials except for CNT.

Siddaiah N[29] MEMS have a wide range of applications, in this approach a new U-shaped cantilever having the measurements 100µm*20µm*2 µm with a displacement of $3.4777*10^6$ µm and performs better than rectangular cantilever. The design is processed in COMSOL and the variation is considered bypiezoresistive along with semiconducting materials.

This article[30],most of the cantilever novel MEMS switch based form used to be considered as proportions have been minimized with the dimension evaluation in order to improve the performance and decrease the pull-in voltage of the MEMS series switch at Ka-Band frequency.The pull-in voltage of the system is lowered in order to provide satellite communication purposes and to analyse them. Various tackle tools like Comsol 5.2 is needed to asses and examine electromechanical, capacitive, RF overall performance and unlike parameter of the device.

The triple coupled cantilever is modelled for simulating bio-sensor for every Eigen mode resonant frequency and distinctive substances found the usage of this bio-sensor [31]. Triple coupled cantilever, actuated the

use of every Eigen state for corresponding Optical excitation and Dielectric pressure gradient approach. Glucose and Fibroblast for triple coupled cantilever, according to the floor amendment can be used asa Bio-Sensor such that the work can, in addition, be prolonged for extraordinary pathogens and sensors based on Protein. Besidesthe DNA base bio-sensors prolonged to PCR and ELISA primarily based checks are executed on Micro stage with the help of Triple couple cantilever.

Here [32], low actuation voltage switch is modelled with electromagnetic and electromechanical properties. It is designed with a characteristic of distinctive parameters. By the commentary from the graphs for the duration of the ON state of return loss, it has a much less than -35 decibels and the insertion loss in ON state is greater than -0.1 decibels at 10GHz frequency. The Isolation in its OFF state has greater than -16 decibels at 10GHz frequency [33].

In the paper [34], the total difficulty ofdetecting exon area detection in a gene sequence is demonstrated. In paper [35]PIT patterned metasurface made of ribbons and strips of graphene are numerically simulated and theoretically calculated, which is due to using negative obstruction involving the super and sub radiant mode. As of the papers [36-39] Kalman filter used for novel noise cancellers of ECG signal enhancement on the contaminated sign and is impartial of tread dimension because of combined Kalman algorithm. Together these aspects compose the projected KNC as a new achievement in the perspective of ECG enhancement. To reap better performance, computational complexity of this algorithm in real-time implementations must be decreased [40-44].

CONCLUSIONS

In this paper, a literature review of detection of VOC sensors and different method are presented among them initially detection of VOC in a conventional method like using metal oxide sensor are mentioned which gave best results for detecting VOC but the methodology is good but these are not compact. The later review focused on MEMS-based design compact size sensor for the detection of VOC were presented with different cantilever beam structures among all the above review papers concentrated on detection of VOC gases like n-octane, toluene & n-but anole, Ethanol, Acetone, Pentaerythritol, tetra nitrate & 2,4,6-Trinitrotoluene with sensitivities were presented by different authors. Authors mainly concentrated on resonant frequencies and quality factor and deflection properties of length Vs width. Lastly, static and dynamic analysis of t shaped cantilever beam has been studied with Fem analysis using comsol tool.

Here I conclude that Detection of VOC can be designed with different beam structures and different length, width, thickness are chosen and can achieve the best sensitivity with miniaturized measurement sensor design devices for the monitoring of different VOC.

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