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Strategic report on MEMS based carbon monoxide sensor technology for environmental air quality monitoring using unmanned aerial vehicle

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Abstract
In an environment the various types of hazardous gases are present such as carbon monoxide (CO), nitrogen dioxide (NO_2), and sulphur dioxide (SO_2) etc. In addition, with these hazardous gases, the vehicle and industry related air pollutions are also the predominant parameters. The CO gas is the most powerful hazard gas mainly affects the human health. So, the main motto of this research article is to provide a strategically measured CO level for low and high range of CO present in the environment using micro electro mechanical system (MEMS) based CO sensing technologies. In the proposed system unmanned aerial vehicle (UAV) is used to measure CO gas in the various altitudes to get an environmental data. The sensor which is used to measure CO is structured with substrate, micro heater, metal oxide semiconductor (MOS) sensing layer and electrode using n-type MOS. The major objective of this research article is to identify the n-type semiconductor to optimize the power. It is used by the MEMS based gas sensor in order to increase the flight time of mini-UAV to measure the CO level in various altitudes and transfer the measured data to the console system for analysis and preventive measures.

Keywords
CO, Environmental air quality monitoring, Metal oxide semiconductors (MOS), MEMS, Mini UAV.

1.Introduction
Carbon monoxide (CO) gas is the hazardous gas to the human society. The properties of CO gases such as colourless and tasteless, while it is explored from the partial combustion of the vehicles that creates a very dangerous health issue such as intoxication to the human society [1−5]. It is very necessary to find the various materials for substrate, hot plate, sensing material to reduce the threat due to the emission of CO. The micro electro mechanical system (MEMS) based CO sensor is fabricated in order to measure its concentration efficiently from the household and industrial environment. Hence, researchers paying more contributions to the sensor technology for the detection of low and high concentration of CO present in the environment [6−8]. Nowadays, the development of micro sensor is very necessary to sense the CO gas exists in the residential areas where the maximum CO gas is emitted.

The use of micro and nano-thin films technology in metal oxide semiconductor (MOS) related sensors plays a major role in CO gas measurement due to its micro-structure from micro-machining. The electrical property of the sensing element changes due to oxidation because of the CO gas reaction with sensing material of MOS based Chemi-resistive sensors. This change in the electrical property of MEMS sensors used to detect the presence of CO. The concept of the detection principle i.e., an adsorption process in MOS substrate which was introduced in the 1960s [9–13]. However, in the last twenty years the design and development of MOS sensors for the CO gas detection is great. At present, these advanced MOS based sensors are used for different application areas such as CO gas detection from the vehicles and air quality monitoring. Thus, the primary advantages of MEMS based Chemi-resistive sensor, includes very less form factor, simple gas detection technique, simple measurement system, easy fabrication and less cost. However, there are several things related to the sensing of CO gas need to be discussed. In that very important one

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is the low concentration CO gas detection, which occurs constantly in the residential areas [14–18]. This is a really challenging technology in order to detect those less concentration CO gas present in the indoor environment and also absorption of such kind of gases leads severe health issue to the human society. Hence, the researchers started giving the contribution to the development of MEMS based sensor to measure the low concentration of CO gas by using the various kind of materials for the substrate and sensing layer of the sensor with different dimensions for the hot plates in MEMS, this leads to very good result in minimum CO detection with good stability and reliability. Nowadays, the optical based CO gas detection comes into the picture and also some of the researchers concentrating on infra-red (IR) based CO detection using the principle of light absorption [19–22]. The main goal is to give the very wide study on the substrate, sensing material, hot plate material, thickness of the hot plate and its temperature distribution for the MEMS based CO sensor used for CO gas detection by the researchers. So, the researchers can develop the sensitivity, stability and other characteristics of the MEMS based CO sensor. In addition to that the air quality monitoring using flying robots, is used to measure the amount of CO gas present in the various attitudes of the household environment and industrial areas with the information about the CO gas can be transmitted to the ground control area from the unmanned aerial vehicle (UAV) sensory system [23–25].

Finally, the primary objectives focussed on

1. Introduce an importance of necessity for CO detection.
2. Describe the need of environmental air quality measuring system using the UAV.
3. Describe the various methodologies used for CO detection based on MOS techniques.
4. Recent trends for CO detection, which mainly focuses the various important sensor characteristics in MEMS sensors.
5. Describes the recent trends in optical method of CO detection.
6. Summary of the various highlights on CO detection techniques which are suitable for efficient environmental gas monitoring.

This article organised as to give the significance of CO gas detection, role of UAV used for atmospheric CO gas detection, various materials used for gas sensor fabrication, recent trends of microelectronic devices used for various atmospheric gases exist in the environment and material selection criteria for UAV application. The outcome of this article is to provide an idea about the selection of material for CO sensors and fabrication with improved optimized power consumption and sensitivity for the smart UAV application

2.Importance of CO gas measurement

The presence of CO gas in the residential environment and industrial environment causes many health related issues to the human. Human beings cannot detect the CO gas present in the environment due the properties of CO gas including colourless and tasteless property. Hence, it is very necessary to measure the CO present in the environment. CO gas is created by both artificial as well as natural sources. In indoor the largest amount of CO gas emission happens in kitchens and in outdoor more CO emissions in high traffic areas and industrial areas. Burning of wood and charcoal generates more amount of CO gas, which mixed in the air and that causes more health issues to the human [21]. The more amount of CO gas created from the burning of fossil fuel. The CO gas from the automotive sources and industry sources creates a long-term exposure to the people, which create severe health issues to the human society [19–23]. There are several chemical reactions take place between CO and some other gases, which are present in the air as well as human blood tissues. The consumption of this air creates health related issues. CO gas reacts with the red blood cell and produces carboxyhaemoglobin which creates issues with the red blood cells of human and hence, there will be lack oxygen distribution to the human body that causes respiratory related issues to the human such as vomiting, hypertension, increase in stress, nausea, laziness, problem related with hearing and sometime it leads to coma [19, 20] and also due to the excess amount of CO consumption causes more health issues to kids, pregnant ladies and so on. One of the dangerous things is that the CO consumption causes death to the human if they consume CO gas for very long duration even a small amount of CO gas for a very long time is dangerous to health and consumption of very high concentration of CO gas for a small amount of time will also lead to death.

Thus, the amount of CO gas can be measured in terms of ppm or mg/m^3. The consumption of large amount of concentration of CO makes problems quickly in primary organs of humans. There is a possibility that even a very small amount of CO consumption for the children for a long duration causes many health-related issues for the kids and pregnant ladies. *Table 1* shows the health issues caused by CO is presented due to various amount CO consumption with duration [19–23].

Table 1 Health issues due to CO gas consumption with duration

S. No.	CO gas concentration in ppm	Exposure time	Heath related issues
1	35	6 to 8 hours	Severe head ache, giddiness, motion sickness, vomiting, loss of concentration
2	100 to 200	2 to 3 hours	
3	400	1 to 2 hours	
4	800	45 minutes	
5	1600	20 minutes	
6	3200	5 to 10 minutes	
7	6400	1 to 2 minutes	
8	1600	2 hours	Respiratory problems, Coma, Death
9	3200	30 minutes	
10	6400	<20 minutes	
11	12,800	<3minutes	

3.UAV system for environmental air quality measurement

UAVs are used to detect the gas leakage detection, environmental monitoring, and pollution mapping applications. Using UAV based air quality measurement is getting popular because of more area can be covered by UAV and the concentration of various gases can be measured in various altitudes in rural and urban areas. This plays a major role in wide areas to acquire the various meteorological data and the acquisition of greenhouse components from the atmosphere, this includes the measurement of methane (CH_4), carbon di-oxide (CO_2) and water vapour components present in the environment [26-29]. The measurement of greenhouse gases such as CO, CH_4 and NO_2, using UAV was done [30]. *Figure 1* shows a simplified illustration of basic data acquisition using UAV which shows the data transformation between environment and ground station using a UAV sensory system where the various types of sensors can be mounted on the UAV for the different types of gas measurement present in the environment.

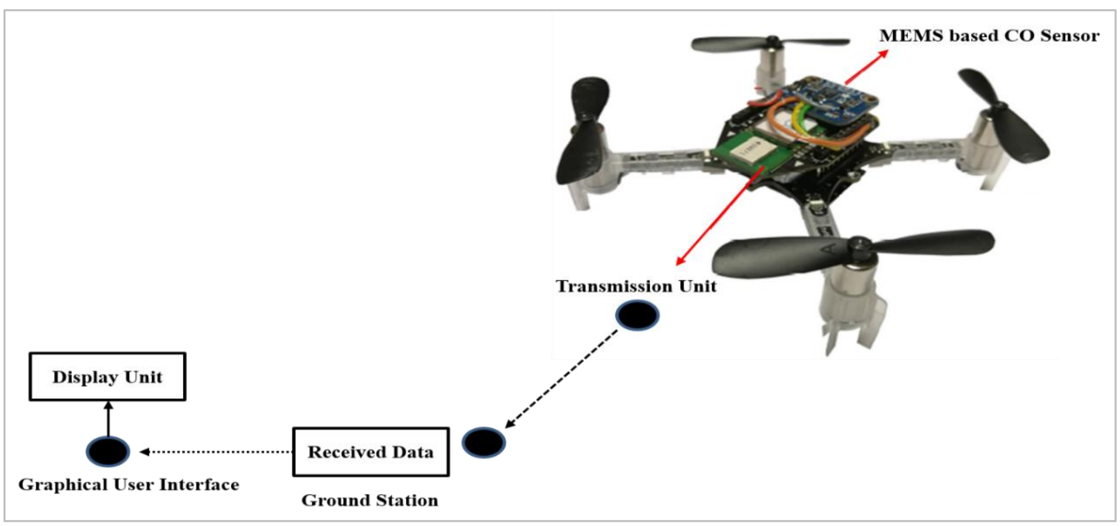

Figure 1 Environmental CO data acquisition system using nano UAV

Commercially available air pollution sensors were mounted in the UAV to measure the various environmental pollutant particles using spiral mobility model technique and the result was compared with local particle swarm optimization strategy. In this UAV based environmental monitoring was based on bacteria movement in the environment. Thus the drone covers the specified area by spiral movement and finally the pollution driven UAV provides significant result [25]. UAV mounted commercial sensor system was used to measure the CO, and different particulate matter

(PM) pollutant present in the school environments. The PM such as PM_1 and $PM_{0.5}$ were measured for five days during occupancy hour and the results were compared with outdoor parameter and finally the hazard index were calculated and due to that the various possibilities of health issues was illustrated [30], Whenever using the MEMS based sensors to measure the air pollutant present in the environment consumes more power due to the use of global system for mobile communication (GSM) module and other related electronic circuits, the work proposed was increasing the performance of photovoltaic (PV) panels on multi rotor copters against the power-to-payload ratio. The commercially available sensors were replaced with MEMS based metal oxide (MOx) sensors to reduce power consumption and that provides faster response and long-term stability, some complexity found due to the disturbance of air turbulence at the time of rotary wing UAV. The detection of the gas was good for the MEMS based MOx sensor. The power consumption by the sensors nominally 76 mW and the flight time about 30 minutes. MATLAB environment was used for energy optimization. Li-ion 1,800 mAh battery was used and the total weight was less than 30g and to get optimized results. The author proposed the system with an optimal monitoring algorithm for gas leakage localization [31]. Small drones are very useful for detection of atmospheric pollutant kind of research because they can densely cover the region to measure the atmospheric parameters those were previously very difficult to detect the environmental parameters with the use of satellite and manned aircraft and so on [32]. The year wise publications from 2007 to 2020 shown in *Figure 2* which shows the number of papers published in the journal from the year 2007 to 2020. In that survey the scientific publication journal and conference paper in the field of UAV for chemical sensing in environment was about less than 20. The primary intention of this work is to provide the bundled information about the current developments in UAV for chemical sensing from the environment, the next part of the paper provides the updated research trends in MEMS based MOX sensors for measurement of CO present in the environment which shall be used in the UAV to measure the pollutant.

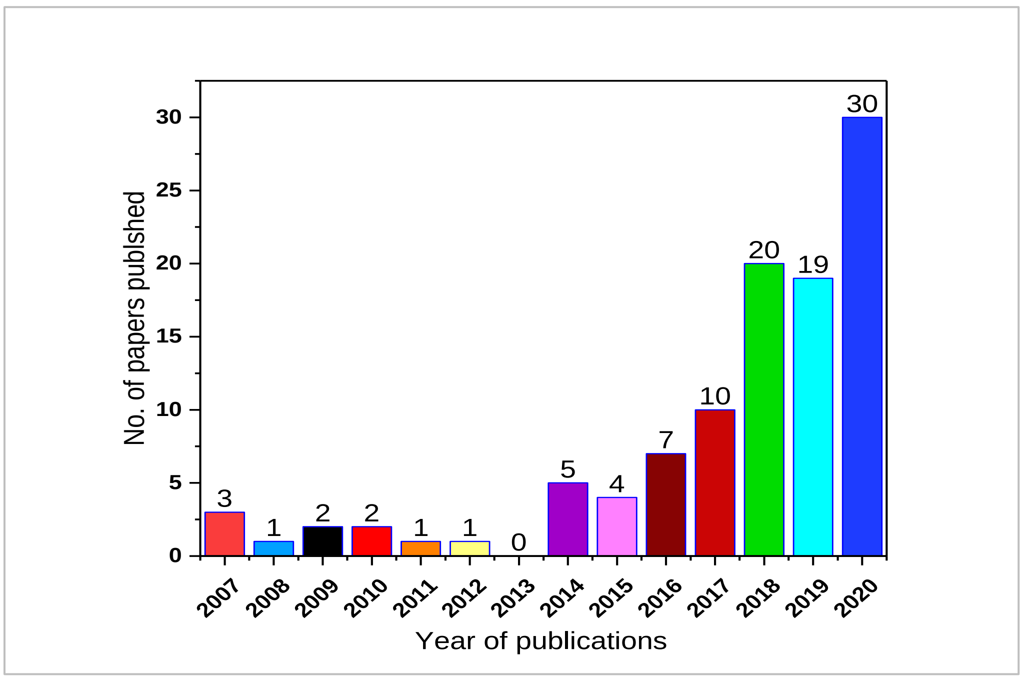

Figure 2 Number of publications with respect to year

The most popular gas sensors used in UAV for measurement of various gas present in the atmosphere are MOS based sensors and amperometric sensors to sense the gas. Thus, the MEMS based MOx sensors were used to detect the environmental pollutant in terms of ppm as well as the sub-ppm level [33]. MEMS based gas sensors having a very good response time of 5 s to 10 s and low power consumption of 15 to 30 mW respectively, and these were further reduced [34] with appropriate characteristics which are suitable to use in UAV.

Tunable diode laser absorption spectroscopy (TDLAS) type of sensor was suitable to use in a UAV application to sense the environmental chemicals due to its speed of sampling, which is about 10 Hz and also it avoids the downwash created by rotary wing UAV [35]. Detection of ethanol vapour in indoor using blimps with MOx sensor system to map in 2 dimensions (2D) was proposed [36]. Recently the non-dispersive infrared (NDIR) sensor was used in rotary wing drones to measure the CO_2at the height about 2,000m [37]. Many researchers are used rotary wing UAV to measure the ratio of CO_2 and SO_2 in volcanic plumes [38]. In order to explore the various advantages of using drones to measure the CO and CO_2, the low-cost sensors were used in rotary wing UAV to derive the emission of carbon particles in the environment smoke plume [39]. Usage of drone mounted with optical particle counters and commercially available air quality sensor system was proposed to measure the various gas pollutants present in the environment such as CO, nitric oxide (NO) and NO_2 at mining areas [40]. Small drones such as micro UAV and Nano UAVs are more suitable to detect the environmental dust particles as well as gas pollutants present inside the buildings [41]. Wireless air quality monitoring using polludrone measures the PM particles such as PM_{10} and $PM_{2.5}$ in Delhi, in that proposed system the PM present in the environment sent to control system using wireless network, the measured PM_{10} and $PM_{2.5}$ using the suggested system was 314 $\mu g/m^3$ and 176 $\mu g/m^3$, respectively [42]. Weight less sensors were used to acquire of total volatile organic compound present in the environment. This sensory system deployed in Nano-UAV, that proposed system designed for developing fleet of a Nano-UAV sensory system to measure the total volatile organic compound in parts per billion (ppb) [43]. Total nine numbers of different air quality measurement sensor system using UAV was developed to measure the environment pollutant such as CO, CO_2, benzene, hexane, PM_{10} and $PM_{2.5}$. Thus, the proposed system provides quick measurement, and the concentration of the various pollutants in different altitudes were obtained in Poland [44]. *Figure 3* shows the proposed method for the micro heater design for MEMS gas sensor and the implementation with micro UAV.

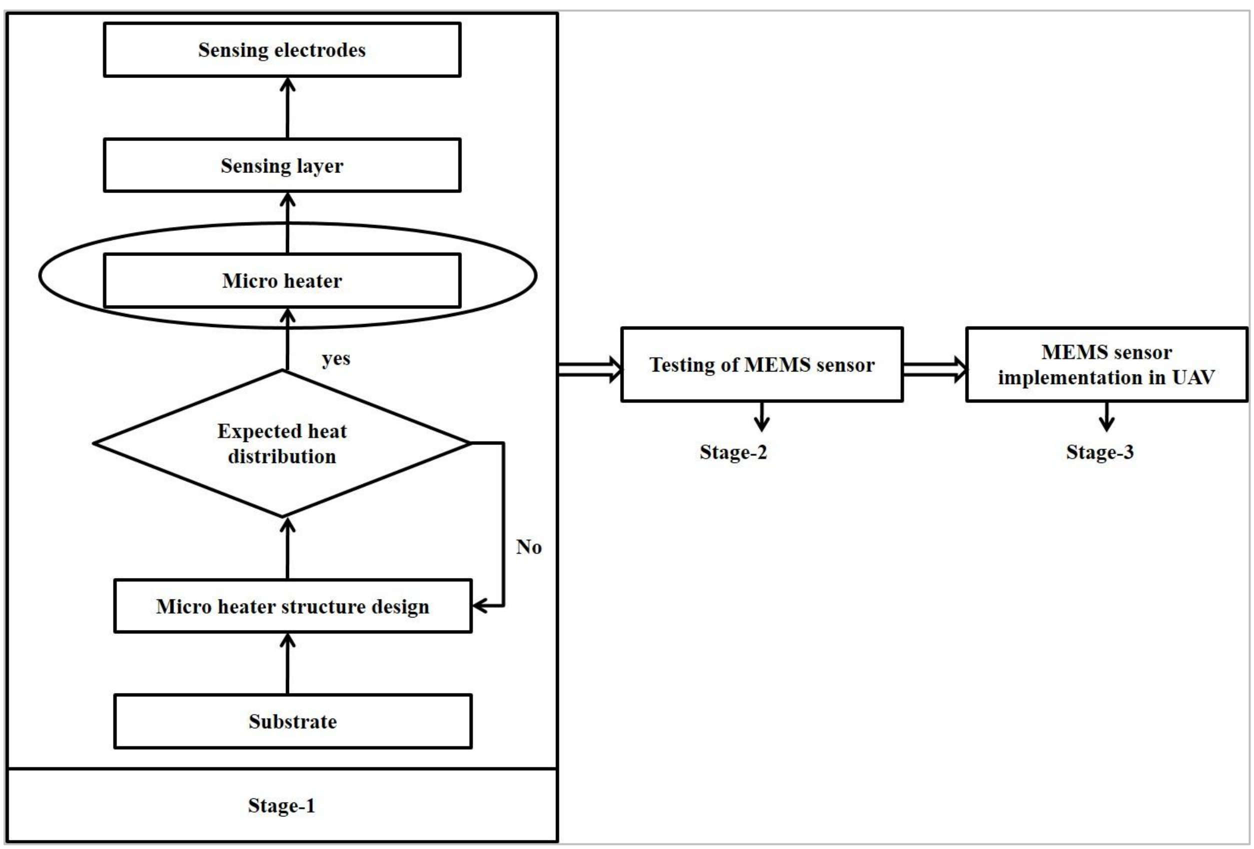

Figure 3 Block diagram of proposed method

4.Detection of CO using MOS

MOS based sensors to detect CO is the most recent trend for the researchers. The attentiveness of the researchers in MOS based sensor design includes the various important characteristics of the sensors such as the sensitivity of the sensor, response time, recovery time, the selection of the target gas, stability, accuracy, fabrication cost and optimized power consumption of the sensor. The researchers giving more attention to provide the optimal solution for each category of characteristics of the sensor. In the process of gas sensing technique which involves more steps, in that the very first one is the MOx layer of the sensor has to identify the detection of CO with the change of electrical properties in the oxide layer of the sensing material. The purpose of target gas was provided by the chemical response with adsorbed Oxygen (O_2) particles as well as CO molecules. Electrical conductivity of the oxide layer in the sensor varies because of the O_2 adsorption in oxide layer present in sensor and this provides as a result of change in resistance at the sensing layer [45−47], thus the change in electrical property is measured to detect the CO level by comparing the electrical property of sensing layer with no reaction of adsorption that means without the presence of CO gas which used to the sensitivity calculation of the sensor [48−55]. The operating temperature of the sensor is directly proportional to the rate of O_2 adsorption. To obtain the required O_2 adsorption, it is essential to have the different operating temperature, due to the consideration of the reliability, lifetime of the sensor and also the optimal temperature should be maintained. The property of adsorption can also be increased by selecting the proper composition of semiconductor material which is also one of the factors of sensitivity. Mostly n-type MOS materials being used for miniaturised sensor fabrication which intends the more n-type sensor availability.

Detailed statistics is given in F*igure 4 and Figure 5* for gas sensors which uses MOS for both ‘n’ and ‘p’ type semiconductor [55]. Most of the MEMS based gas sensors use thin film technology and the combination of MOS thin film and the micro heater provides uniform distribution of the operating temperature of the sensing layer which increases the performance of the sensor. Electrodes are used to measure the resistivity change of MOS for the purpose of measuring the sensitivity of the sensing element.

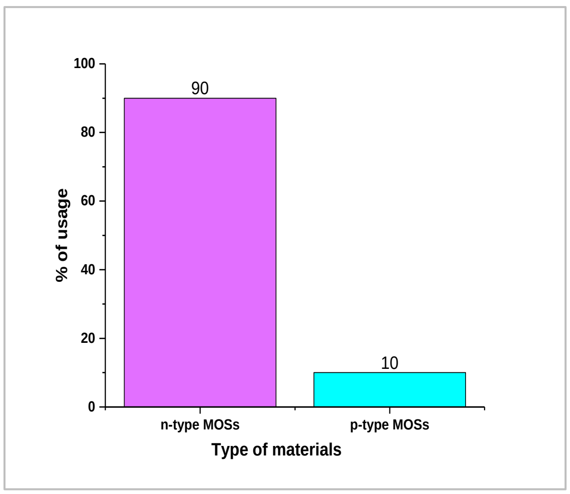

Figure 4 N-type and p-type MOS Used for gas sensors

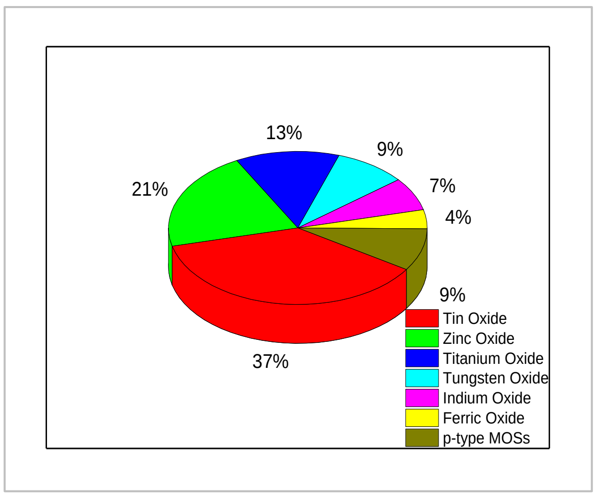

Figure 5 Usage of n-type MOS used for gas sensor

The various characteristics of the sensor such as sensitivity, recovery time and response time which are increased by the uniform distribution of the temperature of the sensing layer and the selection of materials. *Figure 6* shows the basic block diagram of thin film based CO gas sensing system using thin film technology for fabrication of MEMS based gas sensors.

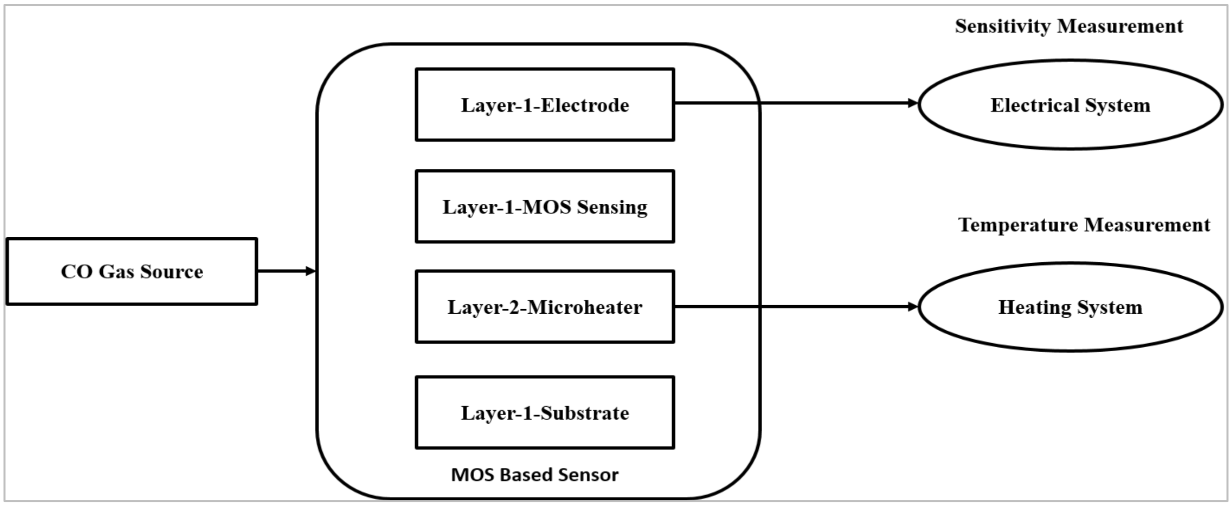

Figure 6 Block diagram of MOS CO gas sensing system using thin film technology

4.1N-type MOS based CO Sensor

Mostly all the sensitive MOx based semiconductors react to CO gas. The basic reaction of O_2 adsorption by the metal used for sensing layer in the sensor gives the change in electrical properties of the layer which is the measure of CO. This chemical reaction is not at the same intensity for all the semiconductor materials. Recently used n-type MOS to measure CO are tungsten oxide (WO_3), titanium oxide (TiO_2), zinc oxide (ZnO), tin oxide (SnO_2), cerium oxide (CeO_2) and indium oxide [52−55].

4.2WO_3 material

Some of the researchers were found that WO_3 is one of the sensitive materials to sense CO gas. The sensitivity of the CO gas was tested using WO_3 as a sensitive layer and for the different oxygen condition the resistivity property of the material varies which shows that the tungsten material is sensitive to the CO gas [56]. Some of the research conducted by the researchers towards the analysis of sensitivity of CO gas on WO_3 doped with other materials in which the author found the sensitivity of CO gas about 100 ppm and 1 ppm of NO_2, to get this result the author used two percentage of vanadium and copper catalysed WO_3 at 400°C and 700°C respectively and annealed them to get the response. However, the sensitivity of ammonia was greater than both CO and NO_2 [57].

4.3TiO_2 Material

TiO_2 is used to detect the CO gas. It was found that this material provides the best sensitivity for CO gas. The electro-spinning method was used for TiO_2 nano fibers and water-soluble polymer polyvinylpyrrolidone (PVP) also used to get the sensitivity of CO gas. Pt electrodes were used in the sensor in the ranges from 175 nm to 250 nm. The calcination temperature (600°C) is one of the major parameters to measure the sensitivity of the CO gas. *Figure 7* shows that the CO sensor also provides very good response for low concentration of CO as 15 ppm. The high density of adsorption in nano-crystalline TiO_2 nano fibers provides the low concentration of the CO gas detection at a very low operating temperature [58].

Nano structured TiO_2 hallow hemisphere type CO sensor was developed through the deposition in room temperature as well as at high temperature. This experiment results around twenty percentage of change in resistance at 250°C for 1 to 500 ppm level of CO and it was compared to TiO_2 thin film technology [59]. MEMS based CO gas sensor was developed using $SnO_2$and molybdenum (Mo) as a micro heater. The researcher is chosen the molybdenum material which has a high melting point and coefficient of thermal expansion and the author fabricated the sensor using those materials. The researcher experimented the joule heating process to vary the temperature in a Mo based micro heater, in between sensing and micro heater layer and the silicon nitride (Si_3N_4) material was deposited to provide the isolation between the two layers. *Figure 7* shows the MEMS based sensor using Mo as a micro heater is giving overview for sensor layers [60].

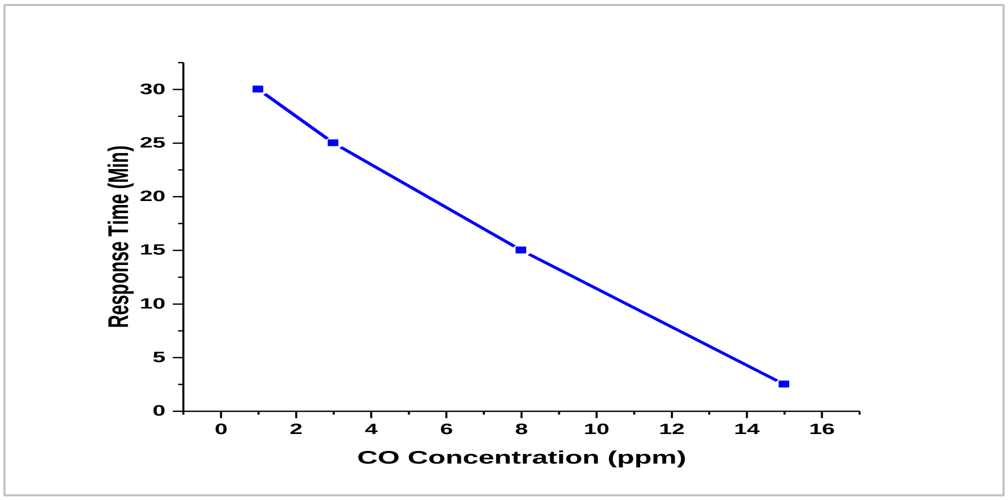

Figure 7 Response of TiO_2 for low concentration of CO detection

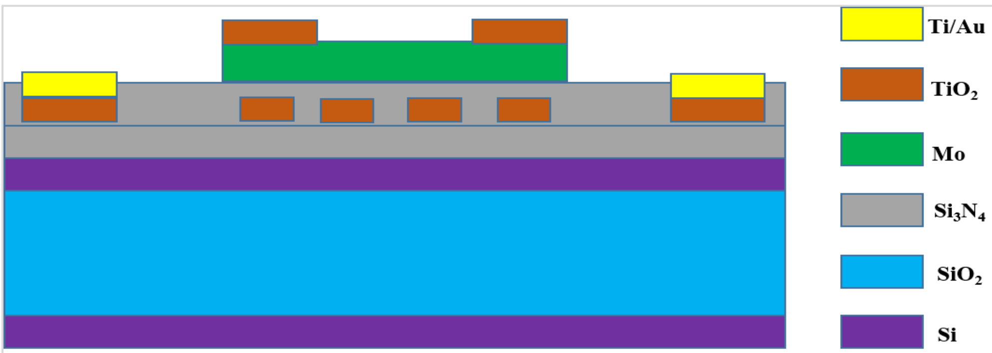

Figure 8 Cross section of MEMS based gas sensor

Very few researchers were used the multi walled carbon nano tubes to detect the CO gas and obtained 50 ppm around 300°C which is seven times greater than pure thin film [61] (*Figure 8*).

4.4ZnO material

Even though ZnO is good sensing material and senses many gases in addition with CO gas, therefore to increase the sensitivity of the CO gas MOx material is doping with ZnO.

4.5SnO_2 material

SnO_2 is the material which is mostly used by the researchers because this n-type MOS material results excellent sensitivity towards the CO gas. So many MEMS based CO gas sensors were designed using SnO_2 material which includes doped, undoped thin films, nano-wire types, nanoparticles type and nano-cluster type. SnO_2 nano-wire based technique results on CO gas for the adsorption of O_2 with around optimised 60 nm of diameter and the author prepared the SnO_2 and N-type nano-wire element. The researcher analysed the conductivity of the material using V-I characteristics and found that, there is an increase in conductivity from the results and constant response time around 35 s. The researchers worked with different level of temperature, even though the optimum temperature did not specified in their work [62].The sensitivity of the designed CO gas sensor was studied with different thickness of the TiO_2 material and it was found that the excellent performance of the sensor were obtained for the thin film thickness about 2.62 nm and beyond the thickness of 2.62 nm tends to zero response in change in resistance of the material, for this sensor design they have used gold (Au) and Platinum (Pt) as the electrodes for the MEMS based CO sensor [63]. The SnO_2 thin film ranges from 50 to 100 nm was deposited on SiO_2 and Silicon (Si) substrate to analyse the response time and the range of CO gas detection. The researcher was used spray pyrolysis method at high temperature and found the excellent response for the very minimum concentration of CO gas which is around 4 ppm at 350°C [64]. The spray pyrolysis method was used to prepare the SiO_2 nano-wire to detect the CO gas and CH_4. Titanium (Ti) and Au was used as a metal contact at the end of the sensing layer, thus the diameter of 30 to 400 nm was used for nano-wires and they analysed the O_2 adsorption at various operating temperature and finally they found that the designed sensor provides good response at 300°C and previously the researchers got the abnormal response from the sensor whenever it was operated below 300°C. *Figure 9* shows the SiO_2 nano wire based CO sensor consists of hot plate, and sensing element with SnO_2 nano wires [65].

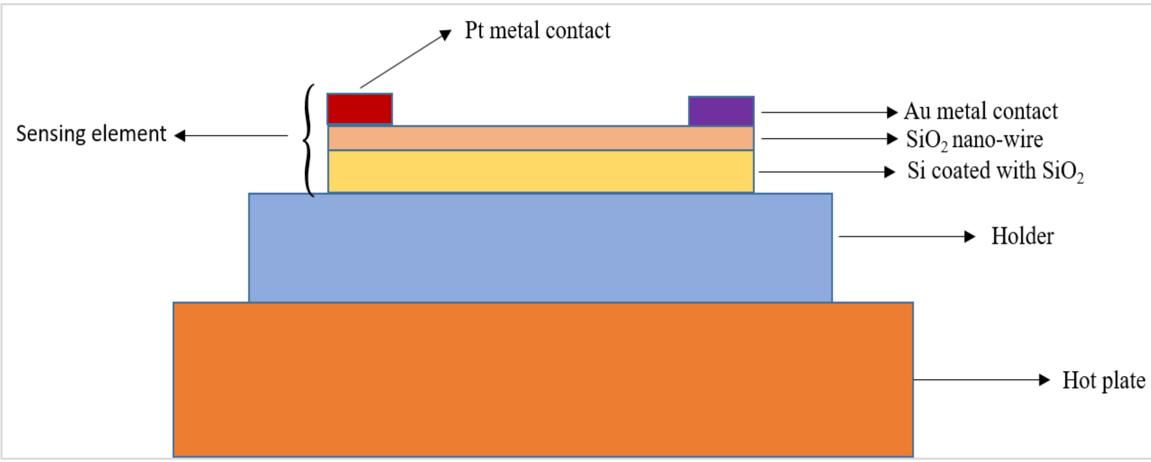

Figure 9 Fabricated MEMS based SiO_2 nano-wire type CO sensor

The researchers worked on the MEMS based sensor for the application of membrane fuel cell. They have worked with SnO_2 thin film to design CO sensor and for the substrate they used stainless steel and aluminium nitride (AIN) for isolation material to design CO gas sensor. Radio frequency (RF) sputtering method was used to deposit the thin film of SnO_2 around in the ranges from 100 to 300 nm. The detection of CO gas was done at various temperatures within the ranges between 100 to 350°C for 100 to 1,000 ppm concentration of reference CO gas. The author observed that the increased sensitivity about 300°C for thickness about 100 nm of thin film deposition. The smaller deposition of SnO_2 results the better O_2 adsorption which gives a better sensitivity of the sensor, and these things were proven by the atomic force microscopy and scanning electron microscopy and also the researchers were observed that the response time and recovery was also better for 100 nm thin film comparatively with 200 nm and 300 nm of SnO_2 thin films. The result gives the optimised temperature of 270 °C to measure the CO gas in the range about 1,000 ppm [66].

4.6 SnO_2 with doped materials

In application wise for the integrated gas sensor, the major characteristics were investigated. The researchers were used copper (Cu) doped SnO_2 with Pt material on top and Cu doped SnO_2 with Pt and Silicon dioxide (SiO_2) layer on the top. The thin film thickness for doped SnO_2 was 3,000 Å, Pt layer thickness about 10 Å and SiO_2 layer thickness around 100 Å. RF sputtering was used to deposit thin film layer at room temperature and was experimented to observe the change of electrical potential per unit time. The author found the optimised response time for the sensor at the various operating temperature.

The good result in terms of response time was obtained for operating temperature about 320°C for the reference CO gas concentration of 1000 ppm. The researchers compared the response time with other operating temperature and reference CO gas concentrations in different cases such that 250°C for 400 ppm, 270°C for 600 and 300°C for 800 ppm, from all the observation they obtained the better response time for higher gas concentration with maximum operating temperature. This might be described as the adsorption property of CO gas molecules increases with higher operating temperature that leads to very good diffusion. The *Figure 10 and Figure 11* shows the response between response times with different operating temperature. [67].

The palladium (Pd) and Pt were used as a doped material with SnO_2, the author was used the heating element as poly silicon on Si substrate. Thus, the thin film doped with Pt and Pd was coated on the upper layer of heating element. The concentration of doped thin film material was about 2 percentage and the heater used to develop the operating temperature about 450^oC to analyse the sensitivity level of the sensor device in dry air. The sensitivity was calculated using the resistivity of the thin film in both presence of CO gas as well as without the presence of CO gas in dry air, *Figure 12* shows that the Pd material has more sensitive to the CO gas than Pt doped thin film.

The nano particle sensor was developed using Pd doped with SnO_2. The reverse micelle technique was used and the researchers found that the palladium oxide (PdO) doped with SnO_2 has good sensitivity with the target gas. The measurements using sensor were done at different temperature ranges from 300^oC to 325^oC, from which they observed the optimum doping concentration of Pd as 0.1 mol percentage with the better output at the operating temperature from 320 to 325^oC [68]. A CO gas sensor was fabricated using Au doped with SnO_2 and the results were observed for different doping concentration of Au. The author was used deposition-precipitation method and tested around ten types of different weightage of Au with SnO_2.

The author examined the sensor sensitiveness at four different operating temperatures with as well as without the existence of CO gas and also the response of sensor was evaluated using the ratio of resistivity of the thin film in air with known value of CO gas concentration. The sensor responses at operating temperatures 83, 100, 160 and 210^oC were obtained for various CO values ranges from 0 to 4,000 ppm. They observed the CO gas sensitivity increases with an increase in operating temperature. *Figure 13* shows the response between sensitivity of two different Au doped thick films with various operating temperatures and the response time with different operating temperature. They observed that the sensitivity of the thick film 1.43 wt. The % of Au doped was more than the sensitivity of the Au doped SiO_2. They have done the study on response time as well as the recovery time of the sensor and they observed that both the sensor characteristics were decreased with growth in operating temperature and also the amount of CO gas concentration [69].

The author was studied about the CO measurement at room temperature. The fabrication of hydrothermally synthesized Au with SnO_2 was done by the author. The author obtained the response of the sensor by varying the different temperature for different concentration of doping in the range of 0.5 to 2 wt. percentage. They obtained the maximum response of the sensor for 1.5 wt. percentage of doping of Au film used for sensor fabrication and they analysed the output with different CO concentration level up to 500 ppm with various relative humidity for measurement. The response time of the sensor for different operating temperature is shown in *Figure 14.* The author was observed the stable reaction of the CO gas sensor for the measurement of CO gas about 500 ppm at normal room temperature and also the author investigated about the selectivity of the sensor using with various gases in front of the CO gas sensor at 50°C and 60°C. The *Figure15 and Figure 16* gives the comparative study of different temperature [70].

The author was experimented the CO gas sensing with multi walled carbon nanotube doped SnO_2. The Author measured the change in resistance of the hybrid nano material in existence of CO as well as non-presence of CO gas to determine the sensor sensitivity. The initial values of the resistances for three different cases of materials were 4.6 MΩ, 0 Ω and 1.3 KΩ for SnO_2, multi walled carbon nanotube and SnO_2 doped multi walled nano tube respectively for the CO gas sensitivity for 100 ppm of CO gas. The author also measured the two different characteristics of the sensor such as response time and recovery time through the measurement of variation in resistivity of the material and they found that the doped SnO_2 and multi walled carbon nanotube has better stability comparatively with a doped SnO_2 [71].

The researcher used SnO_2 doped vanadium material to design a CO gas sensor and they analysed the effect of vanadium with SnO_2 for sensing CO gas. The author used two techniques through activation of O_2 to sense CO gas with adsorption as well as desorption in which both depend mainly on vanadium material doping. The method of co-precipitation was used to fabricate the CO sensor. The characteristics of crystallinity was observed using diffraction of X-ray and finally the author observed the property of less crystallinity exists by doping the higher Vanadium material. They used material Au as an electrode layer and ruthenium (IV) oxide for heater layer. The sensor results of the CO measurement with growth in resistivity of the sensing layer with increase in concentration of O_2 that shows the adsorption of O_2 as well as the N- type behaviour of the vanadium material. The authors studied the sensitivity of the sensor using the various doping concentrations of vanadium and they found the greater sensitivity of the sensor at the temperature of 175 °C for the optimum ratio of SnO_2 and vanadium [72].

The author used calcium as a doped material to design a sensor for the detection of low concentration of CO gas. Sono-chemical method was used to design a CO gas sensor for two different doping concentration of calcium as 5.00 wt. percentage and 10 wt. percentage and the sensor response observed for 30 ppm of CO concentration at the operating temperature of around 350°C. The author was observed the linear sensor response to an increase in CO concentration and the authors found that the optimum temperature for 30 ppm of CO was at 350°C from the change in resistivity of sensing layer. They observed the response time of the sensor was about 25 to 28 s [73].

The researchers were used zinc oxide (ZnO) doped SnO_2 to design a CO sensor to measure the CO content from the environment. They examined the sensitivity of CO gas using ZnO doped SnO_2 nano fibers through electro spinning method. They have experimented with different doping concentration about 0.5 wt. percentage to 5 wt. percentage and they found that the optimum result was recorded for the doping concentration of 1 wt. percentage at 300°C [74].

The author used the copper oxide (CuO) doped SnO_2 to examine the response of the various toxic gases including CO using a fabricated hybrid sensor. They used an electro thermal method to fabricate the sensor and examined the sensitivity and response time of the sensor. They observed the sensitivity of the sensor about 1.2 and reaction time of the sensor was six minutes thirty seconds for CO gas at the temperature about 250°C [75].The researcher was examined the sensitivity of the low concentration CO gas. They used CuO doped SnO_2 to design a sensor and they found the better sensitivity about 95 for the CO gas at the temperature used for annealing as about 600°C. They found the optimum temperature for the CO gas as 235°C for 10 ppm and they got the better selectivity of CO gas among all other gases [76].

The authors examined the CO sensitivity with their fabricated sensor. They used Silver (Ag) and graphene doped SnO_2 for sensor design. The authors were found that the sensitivity was improved after adding some nanoparticles at the concentration about 0.005% for silver and 0.05 % percentage concentration for graphene material at the annealing temperature as 500°C. *Figure 17* shows the comparison of the sensitivity for CO gas sensors using various SnO_2 doped materials. The authors obtained the better sensitivity of the sensor for Ag doped SnO_2 [77].

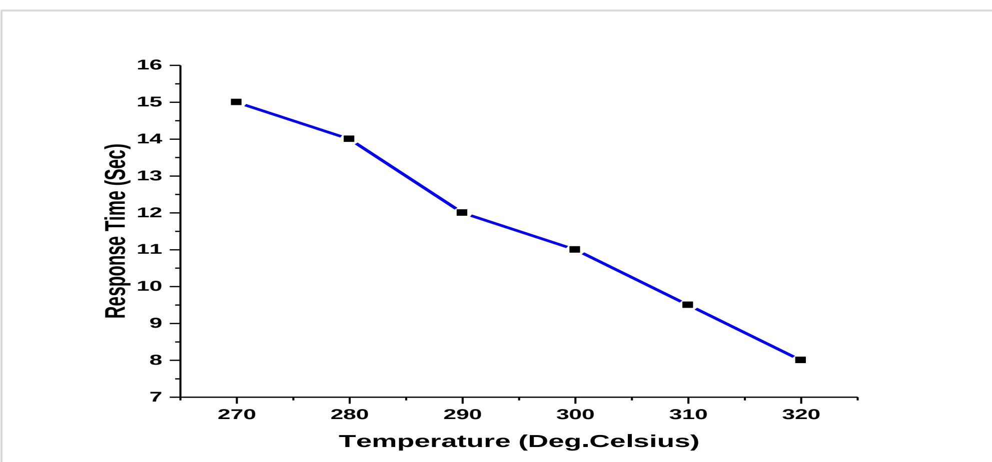

Figure 10 Response between response time vs. temperature for Cu doped SnO_2

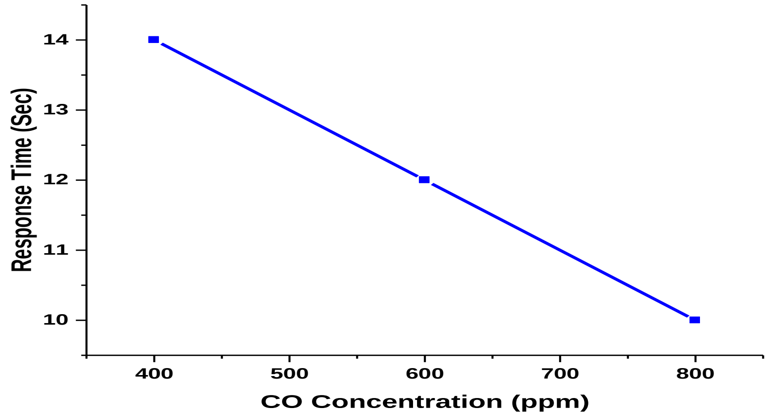

Figure 11 Response between response time vs. CO concentration for Cu doped SnO2

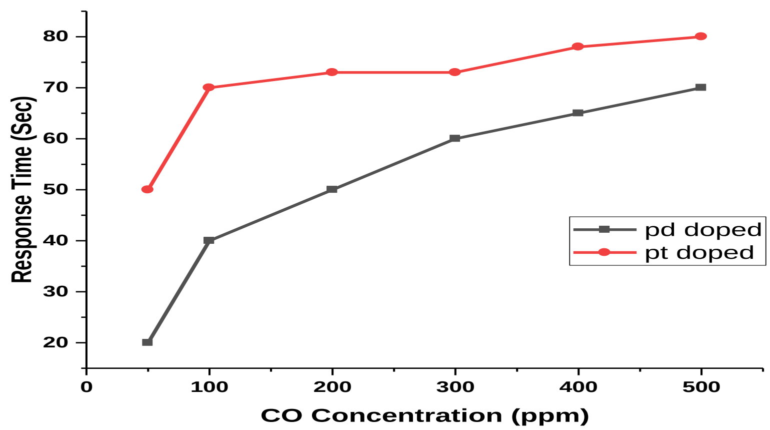

Figure 12 Sensitivity with temperature for Pd and Pt doped with SnO_2

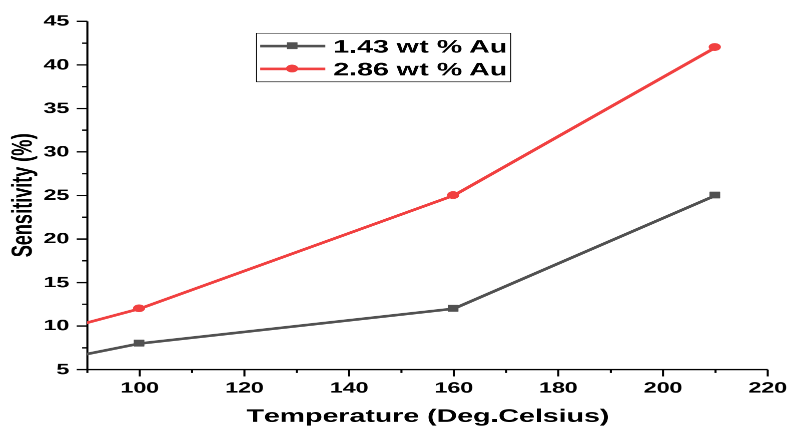

Figure13 Sensitivity of CO sensor for two different Au doped SnO_2 at various temperatures

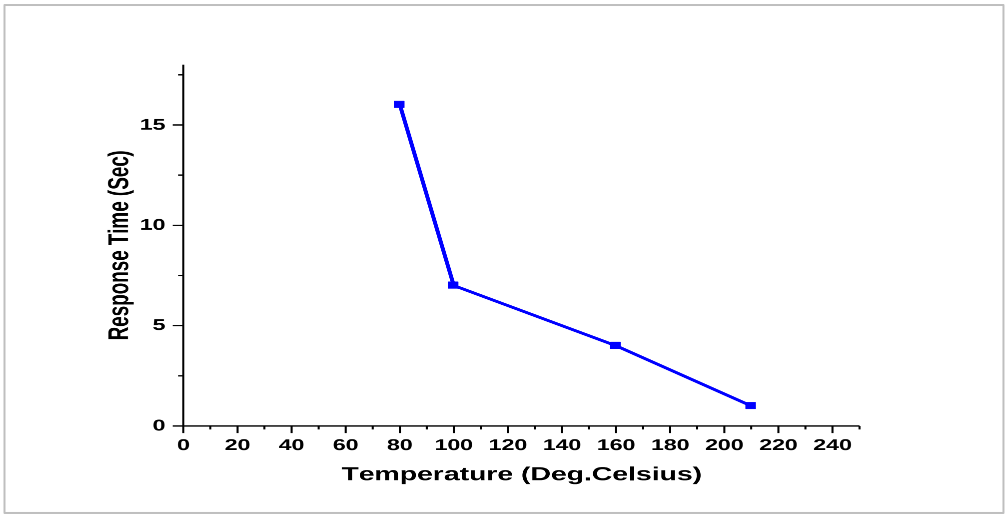

Figure14 Response time of the sensor with various operating temperature

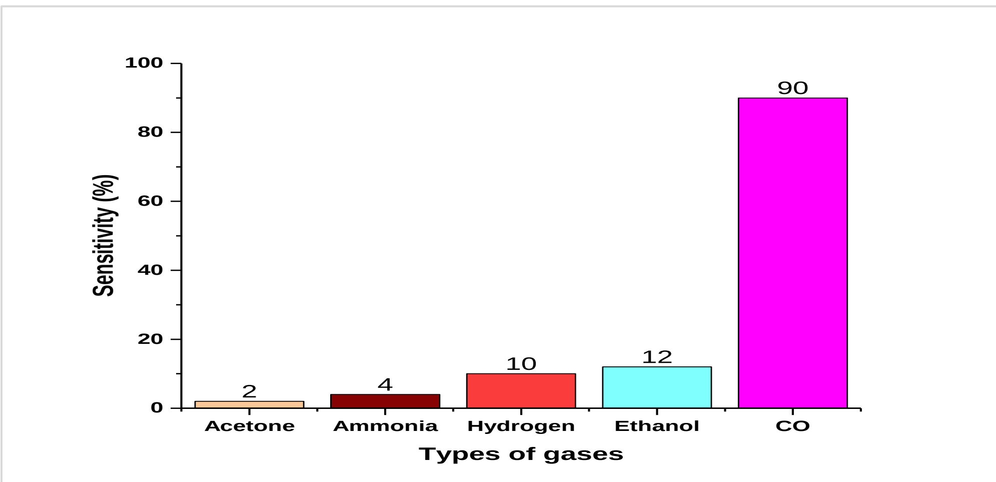

Figure 15 Sensor selectivity in existence of different gases at 50°C

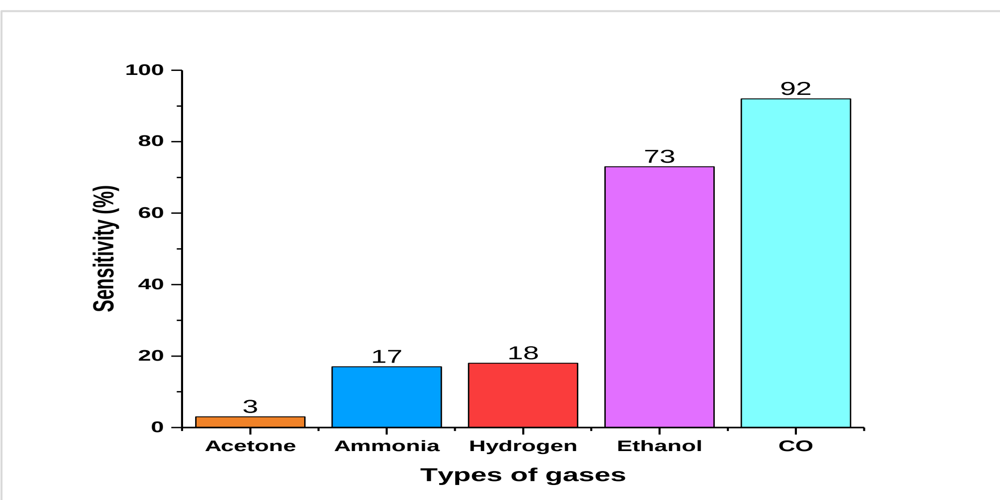

Figure 16 Sensitivity of the sensor in existence of different gases at 60°C

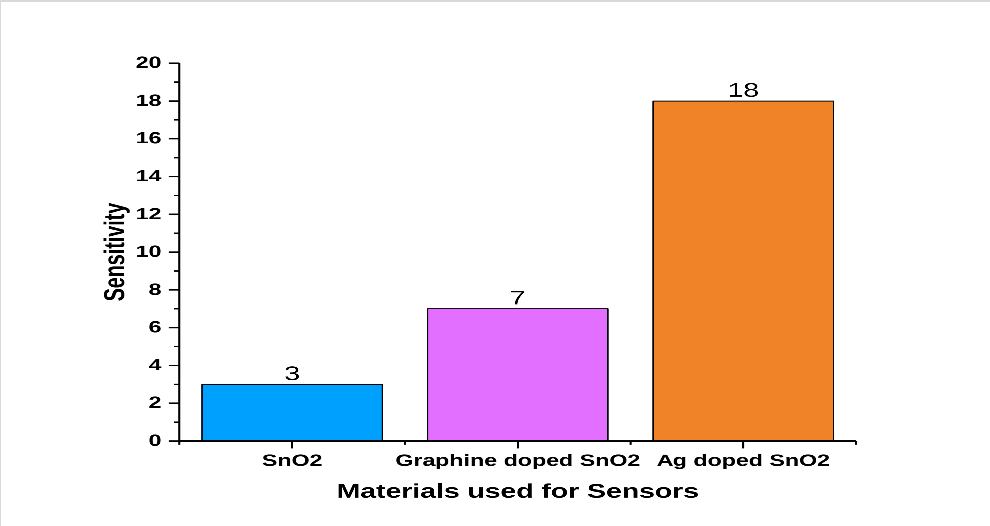

Figure 17 Comparison of sensitivity to various doped material used for the sensor

4.7Summary of SnO_2 based CO Sensor

Figure 18 displays the detailed summary of CO detection using SnO_2 based sensor with doped materials. Sensor sensitivity and operating temperature is presented by reviewing the various research articles which shows the various important parameters of the sensor.

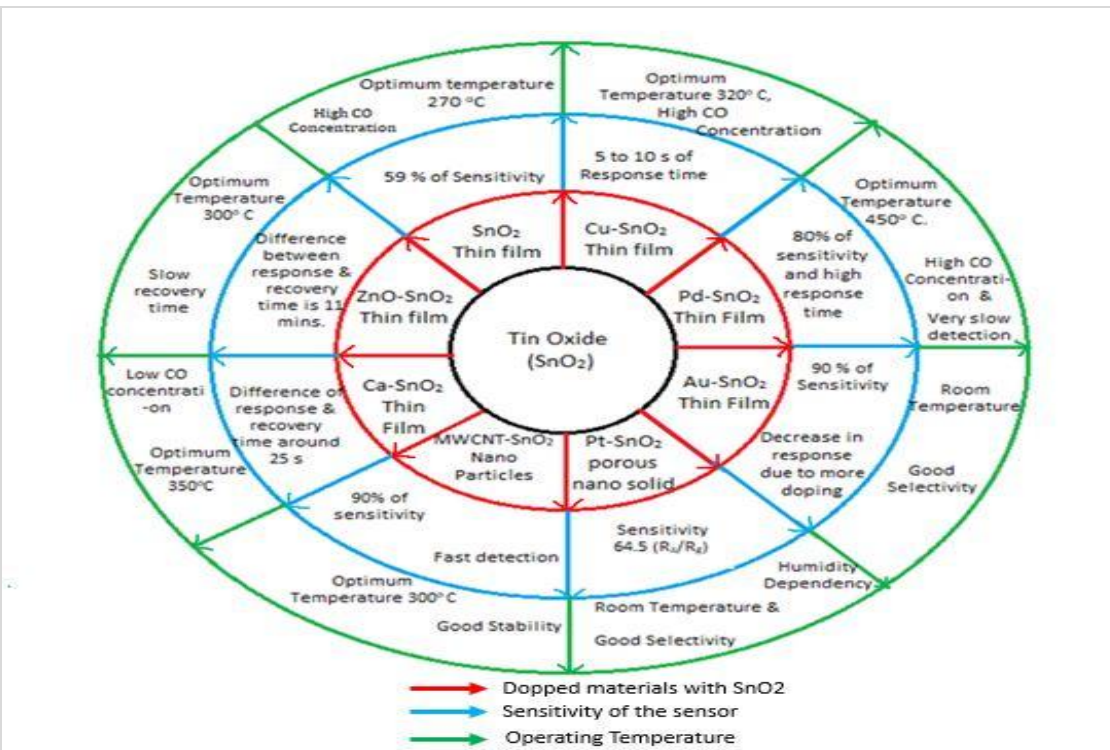

Figure 18 Summary of SnO_2 based Sensor for CO gas detection

4.8CeO2 Doped ZnO_2 Material

The researchers used alumina and silica as a substrate and they deposited the Cerium doped ZnO_2 to design a CO gas sensor. The researcher used Pt as a heater material as well as the electrode layer of the sensor. Sensor sensitivity was observed at higher concentration of CO gas measurement. They observed that for the operating temperature of three hundred and eighty degree Celsius it gives the CO measurement level as ten thousand ppm. The response time were 44 s [78].

4.9 In_2O_3 doped materials

The author used material In_2O_3 to analyse the sensitivity of the CO gas sensor. The sensitivity of the sensor was tested using microspheres at the operating temperature of about four hundred degree Celsius. They found that the sensor was given the very good sensitivity for CO gas lower concentration around 10 to 50 ppm. They examined the sensitivity of the CO sensor with different structures such as hierarchical and hollow type in which the sensitivity for the hierarchical structure of the sensor was 2.1 to 3.8 and the sensitivity for the hollow structured sensor was 1.9 to 2.7. The researchers were analysed the response time for the different structured sensor to measure the CO gas and they found the response time for the hierarchical structured type of sensor was 4 to 8 s and the response time for the hollow structured sensor was 5 to 10 s [79].

In a recent research the researcher used Au doped with ln_2O_3 to design a sensor to sense the amount of CO at room temperature and they observed the sensor sensitivity. The researchers used about four different annealing temperature to examine the sensitivity for the hybrid material. They have observed the highest response of the sensor for the lowest operating temperature about 300°C and also they observed that the reaction of the sensor was considerably good with increasing the concentration of the CO gas and inverse proportionality of humidity at room temperature. The author also examined the selectivity of the sensor in which they have observed that the sensor responding for CO gas was much higher than the other gases tested with the fabricated sensor [80].

5. P-type metal oxide materials for CO gas measurement

The primary part of the resistive shell and the part of semiconductor section works simultaneously in P-type MOx semiconductor. Thus the p-type MOx semiconductor has less conductivity compared with n-type MOx semiconductor because of increased concentration of hole in semiconductor shell. In recent research the p-type MOx semiconductors such as nickel oxide (NiO), CuO, cobalt oxide (CoO) were used for CO detection. P-type semiconductor materials for sensor design is not discussed briefly in this paper due to the lower conductivity of the p- type MOx semiconducting material as well as lower response than the n-type MOx semiconductor material.

6. Recent trends on MEMS based gas sensing technology

Thin film technology was used to design the low power consumption of sensor. Simple meander geometry was used with the thickness of 10 µm. The finite element method was used for the design of sensor. Thus the designed device was suitable for the stationary application of about 707 K heat was generated on the micro heater of the sensor [81]. Lanthanum Orthoniobate powder was used for CO gas detection. The sensing CO gas concentration level was about 50 ppm to 400 ppm, it was observed that the optimum sensor characteristics at the temperature 400°C [82]. ZnO material was used. The researchers were used thin film technology to design CO gas sensor. The Co gas concentration was measured for the various temperature ranges from 160°C to 300°C. The researchers were observed the optimum sensing characteristics at 200°C [83].

Two different materials in different compositions were used to design gas sensor. The material used by the researchers was molybdenum trioxide (MoO_3) and ln_2O_3. The researchers were used spray pyrolysis technique to prepare thin films. The optimum sensor characteristics were obtained at 150°C [84]. Three different materials were used to detect CO gas. The adsorption enhancement was also analysed by the researchers, they developed the simple set up in order to verify the various characteristics of sensor [85]. The researchers were used porous silicon material to design a gas sensor. They were used laser assisted etching process to get the required wavelength and power. Iron reduction process also used in order to add Au nano particles for sensor design to get the desired characteristics of the sensor [86]. The materials CeO_2 nano particles and Ni_2O_3 were used for the research, adsorption of CO was analysed [87]. MOx Semiconductor was used in order to detect the various gases. The researchers were used the hexagonal type geometry. Sputtering technique was used to deposit the sensing material SnO_2 to sense the various gases. The researchers were used the supply voltage about 2 V to 3 V and the power consumed by the sensor was about 3.03 mW [88]. The researchers were studied the effect of stress in MOx material and the finite element method was used for the analysis [89]. The researchers were designed four channel gas sensor structure and MOx material was used the researchers were used sputtering technique for deposition of SnO_2 for the sensing layer. The observed power consumption was about 8.55 mW and the optimised response is achieved for 50 ppm of hydrogen (H_2) as well as ammonia (NH_3) [90].

Silicon (Si) based encapsulation type of optical reflector used in order to improve the sensitivity of the sensor [91]. The researchers were proposed the two column and two array based gas sensor, thus the gas sensor array contains multi channels for gas measurement. The complementary metal-oxide semiconductor (CMOS) technology was used with the sensor area about less than 2 mm. They developed the sensor about to get the gas concentration from 0 to 340 ppm also the minimum concentration of the gas about 0.1 ppm [92]. Low power consumption MEMS based O_2 gas sensor was developed by the researcher using YSZ and porous platinum layer. The observed power consumption to sense O_2 gas was about 80 mW [93].

The researchers were designed MEMS oscillator for gas sensor using piezo electric thin film technique [94]. The MEMS based array of sensor to detect the various gases was developed by the researchers, and they analysed the sensitivity of the sensor with individual as well as combination of the gases [95]. The measurement of ultra-sonic acoustic wave principle was used by the researchers to detect the selective H_2 gas among the various concentration of the gases. The hydrogen gas was detected and the characteristics of the sensor was analysed [96]. The researchers used the H_2 gas sensor to measure the low concentration H_2 at the level about 66 ppm [97].

Poly ethylenimine material was used to develop CO_2 gas sensor. 8 mW power consumption was observed by the micro resonator used by the researchers. The measured range of CO_2 by the sensor was about 1200 ppm to 10500 ppm and the various characteristics of the sensor was analysed [98]. The researchers were studied the various low power micro heater used for MEMS gas sensor and the various characteristics of the low power micro heater were compared by the researchers [99]. ZnO material was used by the researchers to design gas sensor. The ZnO sensing material deposition were done by using physical vapour deposition sputtering method. Ethanol gas chosen by the researchers as a testing gas. The observed sensitivity for the measurement of ethanol gas about 100 ppm. The power consumed by the sensor was 12.17 mW [100, 101].

Pd and reduced graphene oxide (Pd-rGO) composite materials were used to design the nitrogen oxides (NO_x) gas present from the environment. The researchers experimented with four different composite materials with SnO_2 and finally they observed that Pd-rGO thin film has better sensitivity to detect NO_x gas [102]. Silver glue material was used in the die bonding process using gas sensor for MEMS structure study and the different composition of silver glue was used to study the MEMS structure of the sensor by the researchers [103]. In order to Measure the gas flow in industry, the researchers used capacitive MEMS flow gas sensor. The different lengths of micro cantilevers were chosen by the researchers and the ranges about from 50 to 400 µm. The researchers were observed about 3.34 pF to 3.35 pF capacitance changes during gas flow measurement [104]. Mechanical stability of the gas sensor was studied by the researchers. The material used for the gas sensor was chemi-resistive based MOx semiconductor. Thermo-migration effect and the electro-migration effect compared by the researchers [105].

MOx semiconductor with a wrapped-cantilever was used to design gas sensor array and doped SiO_2 material was used to make cantilever for gas sensor. The static power consumption was observed by the researcher was about 5.81 mW [106]. CMOS MEMS technology was used and parylene-C coating was used to develop a gas sensor, the observed sensitivity of the gas sensor was about 171 mV/ (m/s) V and the power consumption was 18.3 mW [107]. ANSYS software was used by the researchers to analyse the structure of the MEMS gas sensor, the temperature distribution was also analysed in order to get the thermal design of MEMS based gas sensor [108]. MOS technology was used to design multi-channel gas sensor with low power consumption, the researchers were used T-Shaped and bridge type geometrics for micro heater. SnO_2 material was used and the sputtering method was used for deposition. The sensor was very efficient to measure CO gas with the power consumption was about 21.92 mW [109].

Graphine material was used to design conductivity detector for gas sensing application multi-layer graphine was used to sense the low concentration of gas. The power consumption was observed by the researchers about 26 mW to detect the higher concentration of pentane gas [110]. Sensitivity of capacitive type gas sensor was analysed using finite element method and Q3D simulations. The researchers observed that the sensitivity of the sensor was improved with width of the film [111]. Micro fluidic type gas sensing device was designed to detect CO gas. The geometry and the heat distribution analysis were done by the researchers using COMSOL software. The supply voltage to the MEMS gas sensor was about 1.2 V and the observed temperature was 640 K [112]. Material Si was used to design array of MEMS based gas sensor to detect hazardous gases and the physical strain analysis of the sensor was done by the researchers [113]. Poly silicon material was used to design sensor. The output of the sensor is observed with the change in the resonant frequency of the sensor [114].

CMOS fabrication technique was used to design MEMS based gas sensor. The analysis of 2D material for MEMS gas sensor fabrication were done with Transition-metal dichalcogenide (TMD) and arsenene materials [115]. MEMS based gas sensor arrays was developed by the researchers with different types of models and analysis [116]. Mxene type of 2D materials was used to design gas sensor. The researchers studied about the characteristics of different materials such as MOx, polymers, 2D nano materials including mxene for the optimised design of gas sensor [117]. Characteristics of graphitic carbon nitride and graphene were analysed for the design of MEMS based gas sensor, the researchers suggesting the 2D materials for the fabrication of MEMS gas sensor in order to get good sensitivity and selectivity with other optimized characteristics of the sensors [118].

Metal organic frame (MOF) work based devices was proposed by the researchers. The various challenges and opportunities for MOF based devices were discussed [119]. The sensor device was fabricated using micro fabrication technique , the researchers was used vanadium oxide thin film as a sensing layer using RF sputtering method and the sensors structure was analysed using scanning electron microscopy [120]. The sensors using bismath – based materials was reviewed by the researcher in which both p-type and n-type attributes were discussed and the future scope also discussed by the researchers [121]. The MEMS based gas sensors using SnO_2 nano materials for low concentration gas measurement was discussed. The researchers given suggestions for future MEMS based sensor development through gas adsorption property and the reactivity of the sensor [122].

The review work was carried out by the researchers on MEMS based gas sensor using organic nano materials and carbon nano tube materials [123]. The researchers were contributed on heme-based sensors for the detection of small O_2 molecules [124]. Different types of nano-materials characteristics were reviewed by the researchers in order to design MEMS based gas detection device [125].

COMSOL multi physics software was used to analyse the sensor material characteristics Ag – based sensing analysis was done by the researcher [126]. An UAV was used to monitor the environmental parameters with commercially available sensors. The unique algorithm was developed by researchers [127]. The concentration of CO_2 gas in the environment was monitored by UAV. The commercially available CO_2 sensor MQ arduino UNO platform [128]. The Concentrations of various hazardous gases were measured and analysed using commercially available sensors [129]. CH_4 gas sensors was developed using thermo catalytic gas sensors. The power dissipation observed by the researchers was about 70mW and the average power consumption was observed as 2 mW [130]. The researchers were developed the UAV network with UAV concept in order to transmit the live atmospheric data to the user. The various commercially available gas sensors were used such as NO_2 gas sensors, volatile organic compound detectors, CO sensors and SO_2 sensor [131].

Table 2, shows the various attributes of MEMS based gas sensors such as gas sensors used to measure the various gases, method of measuring the environmental parameter, advantages and limitations. The last three years of research articles were taken for the advantages and limitations with various methods of measuring principles. *Table 3* Shows the inclusion and exclusion criteria for this strategic investigation on chemi-resistive based MEMS sensor. *Table 4* shows the recent publications on MEMS based gas sensor in various reputed international journals, conferences published by different publishers and it was discussed section 6.

Table 2 Summary of advantages and limitations of MEMS gas sensor

S. No.	Type of MEMS gas sensor	Approaches used	Advantages	Limitations
1	Micro heater for electro chemical sensor	COMSOL multiphysics tool 4.3 used for simulation	707 K temperature was produced for the input voltage of 1.25 V [81]	Less Temperature distribution for gas sensing applications
2	MOx gas sensor	COMSOL software used for analysis	Less stress on material for gas sensing applications [89]	Applicable for minimum temperature
3	MOx gas sensor	Sputtering method	8.55 mW power consumption for gas detection [90]	Different input voltage supply needed for the different target gases.
4	MOS gas sensor	Fixed resistance measurement	Programmable input voltage for different target gases with 8- bit accuracy [92]	Less concentration of gas detection.
5	YSZ gas sensor	Sputtering method	80 mW power consumption for O_2 gas detection [93]	Not suitable for very less concentration of gas detection
6	Capacitive micromachined ultrasonic transducers	Attenuation measurement of ultrasonic acoustic wave in gas	Good selectivity [96]	Only detects greater than 0.05% of H_2 from other gases
7	Micro resonator based MEMS gas sensor	Based on output from micro resonator	Less power consumption about 8mW and less recovery time [98]	Used only for high concentration of CO_2 gas
8	Bridge type MEMS gas sensor	Sputtering technique	12.17 mW for 100 ppm of ethanol detection [100]	Only having good sensitivity for 100 ppm
9	CMOS based MEMS gas sensor	IR adsorption	Very small change in electric potential also can be measured [101]	Used for less concentration of CO_2 gas with less selectivity
10	CMOS based MEMS thermo resistive flow gas sensor	Sputtering technique	Less power consumption about 18.3 mW and good sensitivity [102]	Used for less concentration of gas sensor.
11	Capacitive micro cantilever based MEMS gas sensor	Change in capacitance detection.	Good sensitivity in terms of pF/m/s [104]	Suitable for closed path gas detection
12	MOS gas sensor array	rolling of stressed heterofilms technology	Less power consumption about 5.81 mW [106]	Suitable for less concentration of ethanol in air about 100 ppm
13	CMOS based thermal flow MEMS sensor	CMOS MEMS technology	Less power consumption about less than 20 mW [107]	Suitable for indoor gas sensing applications.
14	CMOS based MEMS gas sensor	Finite element method using ANSYS software	Good temperature distribution from the micro heater [108]	Limited in sensitivity and selectivity
15	MOS gas Sensor.	Sputtering technique	Less power consumption about less than 22 mW [109]	Different input voltages used for detection three different gases
`16	Gaphine based MEMS gas sensor	Sputtering method	Less power consumption about less than 27 mW [110]	Suitable for low gas concentration detection
17	MEMS based inter digital gas sensor	COMSOL and Q3D Multiphysics simulations	Good sensitivity [111]	Relatively high power consumption.
18	Micro fluidic based CO gas sensor	COMSOL multi physics 5.3.	Good temperature uniformity by micro heater, high sensitivity and selectivity [112]	Limited Temperature distribution around 630 K with input voltage of 1.2 V.
19	PolyMUMPS- based gas sensor	Multi-Users-MEMS-	Good quality factor	Suitable for trace gas

S. No.	Type of MEMS gas sensor	Approaches used	Advantages	Limitations
		Process	and sensitivity. [114]	detection.
20	MEMS sensor using 2D materials	CMOS fabrication technique.	High sensitivity [115]	Suitable for low gas detection
21	Graphine based MEMS gas sensor	Sputtering method	High sensitivity and selectivity [118]	Suitable for low gas detection
22	Heme based gas sensor	Heme based gas sensing	Detection of small molecules such as O_2, CO,NO and CN [124]	Used only for bio analysis
23	Plasmonic based gas sensor	COMSOL Multi physics	Good Sensitivity [126]	Selectivity among the various gases is limited
24	MOx based gas Sensors	Based on data acquisition of environmental data.	Airflow of drones with change in temperature and humidity of air given for the trajectory of the drone [127].	The altitude and the measuring sensitivity of the gases are limited
25	MQ 135 gas sensor for CO detection	Acquisition of environmental data using arduino uno with low cost RF module	The environmental data acquisition at various altitudes using drones were carried out [128].	The accuracy of measured data is limited

Table 3 Inclusion and exclusion criteria

S. No.	Inclusion criteria	Exclusion criteria
1	Considered only the peer reviewed articles which are related to this particular topic.	Commercially used sensors for gas measurement and its characteristics.
2	Mainly focuses on sensor power consumption, materials used, techniques used for fabrication and working temperature.	Cost and life cycle of the sensor
3	UAV used for air pollution monitoring.	Blimp based air pollution monitoring
4	Other hazardous gases measuring principles with CO gas also discussed.	Linearity and frequency response of MEMS gas sensor

Table 4 Year wise category and publisher

S. No.	Reference No.	Year of publication	Category	Publisher
1.	81	2021	Journal	Springer Nature
2.	82	2021	Journal	Elsevier
3.	83	2019	Journal	IOP Publisher
4.	84	2020	Journal	Inderscience
5.	85	2022	Journal	Journal of hazardous materials
6.	86	2021	Journal	Elsevier
7.	87	2022	Conference	Elsevier
8.	88	2021	Conference	IEEE
9.	89	2021	Journal	IEEE
10.	90	2021	Conference	IEEE
11.	91	2021	Conference	IEEE
12.	92	2021	Journal	IEEE
13.	93	2021	Journal	IEEE
14.	94	2021	Conference	IEEE
15.	95	2021	Conference	IEEE
16.	96	2021	Conference	IEEE
17.	97	2021	Conference	IEEE
18.	98	2021	Journal	IEEE
19.	99	2021	Journal	IEEE
20.	100	2021	Journal	IEEE
21.	101	2021	Conference	IEEE
22.	102	2021	Journal	Scientific Reports

S. No.	Reference No.	Year of publication	Category	Publisher
23.	103	2021	Conference	IEEE
24.	104	2021	Journal	IEEE
25.	105	2021	Conference	IEEE
26.	106	2021	Conference	IEEE
27.	107	2021	Journal	IEEE
28.	108	2021	Conference	IEEE
29.	109	2022	Journal	IEEE
30.	110	2021	Conference	IEEE
31.	111	2021	Conference	IEEE
32.	112	2021	Conference	IEEE
33.	113	2022	Conference	IEEE
34.	114	2021	Conference	IEEE
35.	115	2021	Conference	IEEE
36.	116	2021	Journal	IEEE
37.	117	2021	Journal	Royal Society of Chemistry
38.	118	2022	Journal	Hindawi
39.	119	2022	Journal	Wiley
40.	120	2021	Conference	IEEE
41.	121	2021	Journal	Springer
42.	122	2022	Journal	Science Direct
43.	123	2022	Journal	iScienceIN
44.	124	2022	Journal	MDPI
45.	125	2022	Journal	American Scientific Publisher
46.	126	2021	Journal	Springer
47.	127	2021	Journal	ACM
48.	128	2021	Conference	IEEE
49.	129	2022	Journal	NEPT Journal
50.	130	2021	Journal	MDPI
51.	131	2022	Journal	Elsevier

7.Discussion

In semiconductor material wide varieties of p-type and n-type materials were used for the design of gas sensor was discussed, in which MOS materials play a vital role to design a MEMS based gas sensor in order to get optimised characteristics of the sensors. In n-type 90% MOS materials and 10% of p-type materials were used for miniaturised sensor fabrication. In p type lower conductivity and lower response characteristics are the major limitations. However, NiO, CoO materials were used for CO detection. WO3, TiO_2, ZnO, SnO_2 and CeO_2 were mostly used n-types MOS materials to fabricate the MEMS sensor. A comprehensive discussion was given to the recent materials used for fabrication of MEMS gas sensor in terms of techniques involved in the fabrication, material usage, advantages and limitations. Inclusion and exclusion criteria were discussed in this paper as a strategic investigation on Chemi-resistive based MEMS sensor.

A complete list of abbreviations is shown in *Appendix I.*

8.Conclusion

The primary aim of this work is to review the MOx based CO gas sensor to measure the concentration of CO gas in indoor as well as outdoor environment. It is very important to identify which material is more suitable in view of the various characteristics of sensor for the application of micro-UAV system to measure the CO concentration in various altitudes of the environment. The main intention of this work is to design and fabricate the power optimized MEMS based CO gas sensor which is suitable to implement in mini or micro-UAV with increased sensitivity and selectivity of MOx semiconductor-based CO sensor. COMSOL multi physics modelling and sputtering method in terms of fabrication were the most commonly used approaches by the researchers in order to get the significant accuracy for sensor characteristics and the outcome of this paper gives the significance of CO measurement and to use it in UAV system.

However, the availability of commercial sensors is suitable only for ground-based air quality monitoring systems and those sensors are not suitable for the micro-UAV application due to its high-power consumption and hence the MEMS based gas sensors gives a significant contribution to reduce the pay loads of a micro UAV as well as the less power consumptions which leads to the UAV endurance capability. In this paper the different type CO sensors based on the various performance characteristics have been discussed to select the appropriate MOx semiconductor based CO sensor for UAV application. As the outcome of this article gives an idea about to select the appropriate material to design and fabricate the CO sensor to give a greater sensitivity of the target gas in the environment. The sensor performance varies depends on the selection of material, structure, operating temperature, doped materials etc. The doping materials such as Au, Cu, Pd, Ag, Al and Ga etc. and some other selective materials are graphene and multi – walled carbon nanotubes. The MOx semiconductor materials gives the more impact on the sensor sensitivity. At present scenario the low cost MOx semiconductor based gas sensors plays a vital role to detect the poisonous gas in the environment. Pure undoped materials such as SnO_2 and TiO_2 gives very good response to the CO gas present in the environment comparatively with other pure MOx semiconductor materials. The TiO_2 based MEMS sensors gives around 84 percentage of sensitivity to CO gas. However, it requires the in-built integrated micro heater to attain a higher operating temperature. The higher operating temperature not required for CO gas sensor for the Pd and Pd doped SnO_2. This survey is very useful to select the suitable SnO_2 doped material and other MOx semiconductor based CO sensor for the required application and also research is needed on that to get the optimum result for UAV applications. The limitations of this study is the selectivity of the sensor and it is concluded that the CO sensor using n-type MOx semiconductor materials are more suitable for CO detection in the different altitudes of environment using micro or nano UAV system.

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Conflicts of interest
The authors have no conflicts of interest to declare.

Author's contributions statements
Vinoth Kumar V: Conceptualization, investigation, writing – original draft, writing – review and editing. **Sasikala G:** Conceptualization, investigation, analysis, supervision and editing.

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Appendix I

S. No.	Abbreviations	Description
1	2D	2 Dimension
2	Ag	Silver
3	Al	Aluminium
4	AlN	Aluminium Nitride
5	Au	Gold
6	CeO_2	Cerium Oxide
7	CH_4	Methane
8	CMOS	Complementary Metal-Oxide Semiconductor
9	CO	Carbon Monoxide
10	CO_2	Carbon Di-Oxide
11	CoO	Cobalt Oxide
12	Cu	Copper
13	CuO	Copper Oxide
14	Ga	Gallium
15	GSM	Global System for Mobile Communication
16	H_2	Hydrogen
17	IR	Infra-Red
18	ln_2O_3	Indium Oxide
19	MEMS	Micro Electro Mechanical System
20	Mo	Molybdenum
21	MOF	Metal Organic Frame
22	MoO_3	Molybdenum Trioxide
23	MOS	Metal Oxide Semiconductor
24	MOx	Metal Oxide
25	NDIR	Non-Dispersive Infrared
26	NH_3	Ammonia
27	NiO	Nickel Oxide
28	NO	Nitric Oxide
29	NO_2	Nitrogen Dioxide
30	NO_x	Nitrogen Oxides
31	O_2	Oxygen
32	Pd	Palladium
33	PdO	Palladium Oxide
34	Pd-rGO	Palladium and reduced Graphene Oxide
35	PM	Particulate Matter
36	ppb	Parts Per Billion
37	Pt	Platinum
38	PV	Photovoltaic
39	PVP	Polyvinylpyrrolidone
40	RF	Radio Frequency
41	Si	Silicon
42	SiO_2	Silicon Dioxide
43	Si_3N_4	Silicon Nitride
44	SnO_2	Tin Oxide
45	SO_2	Sulphur Dioxide
46	TDLAS	Tunable Diode Laser Absorption Spectroscopy
47	Ti	Titanium
48	TiO_2	Titanium Oxide
49	TiO_3	Titanium III Oxide
50	TMD	Transition-Metal Dichalcogenide
51	UAV	Unmanned Aerial Vehicle
52	WO_3	Tungsten TriOxide
53	ZnO	Zinc Oxide