
A Review on efficient gas sensors for sustainable development via detection of various toxic gases

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Abstract

High performance gas sensors are required in order to reveal the presence of large number of lethal gases present in atmosphere. The gas sensor's performance is characterized by high sensitivity and selectivity of certain gases. Currently, gas sensors based on solid-state technology have shown the outstanding process. Solid-state based gas sensors have also numerous merits in medical and chemical field, environmental protection, humidity detection etc. for which oxide based sensors have been mainly used. In addition to this, integrated gas sensors have also found to be useful for the recognition of certain gases, consequently reduction in reproducibility and mismatch errors among sensors have occurred. Finally, the chapter ends with literature of performance of various oxide based gas sensors and their potential application in detection of certain gases.

Keywords: Solid-state Gas Sensors, integrated gas sensors, toxic gases, oxide gas sensors, fire detection, temperature range.

1. Introduction

From last few decades, there has been an incremental effort in developing gas sensing based devices in order to detect toxic gases, as well as in monitoring of manufacturing processes[1]. A lot of gases are being used as raw materials in industries. Therefore, it is quite important to design of highly sensitive gas sensors[2]. These gas sensing based devices is used to monitor the presence of gases and also reveal the concentration of different gases in the surroundings. However, inaccuracies and non-producible results of gas sensors have been concerning issues. Therefore, there is more focus on to simultaneous enhancement in the sensitivity and reliability of gas sensors[3]. Along with effectiveness, cost effectiveness parameter should also be taken into consideration while development of gas sensors. From large number of gases, the gases needs to be observed are Nitrous oxide (NO), Carbon mono oxide (CO), ozone (O₃), ammonia (NH₃), Sulfur di-oxide (SO₂), Methane (CH₄) etc[4].

From quite some time, the role in detection and measurement of Nitrogen oxides based gases has

been increased due to its emission from automobiles and industries. Another toxic gas to be considered is SO_2 . In order to do local monitoring of gases, gas sensing based devices needs to be developed having compact size and also cheaper than the instruments currently being used[5]. Therefore, it is vital to reveal the low concentration of NO and NO_2 based gases in open atmosphere.

Carbon mono-oxide is emitted in automobile exhaust as a result of incomplete combustion of fuels. It is dangerous gas due to its colorless and odorless. In addition, CO_2 gas also causes greenhouse effect and raising the temperature of environment. Therefore, concentration monitoring of CO_2 gas is progressively demanded from society, which can be done by particularly controlling environment, agricultural development as well as bio-related processes[6].

Despite development of large number of gas sensors, ozone gas detection sensors are still lacking[7]. Due to low concentration limits of O_3 , there should be high values of sensitivities and selectivity[7]. Additionally, hydrocarbon gases have evidenced cases of hazardous effects due to the explosions by leaks, which have been used in fuels for domestic purposes. So far, humidity has been sensed via large number of materials[8]. Among large number of materials, physically and chemically stable metal oxides based materials have been broadly explored for revealing humidity at both higher and room temperatures[9]. Thus, there is numerous gas sensing based materials which can help us to reveal the presence of toxic gases. In this chapter, we have discussed various types of gas sensors and further a brief discussion on various oxide based gas sensors have been given with their applications.

2. Importance of solid-state based gas sensors

The mandate for better environmental protection has enhanced activities for solid-state based gas sensors[10]. In past several decades, accidents have been caused due to toxic gases. Therefore, in order to sense the availability of such toxic gases, solid-state based gas sensors are required. Among all the gases, detection of CO gas is extremely important. Although tin oxide (SnO_2) and zinc oxide (ZnO) materials have been used to decrease gases, many efforts have also been made to improve gas-sensing material's performance such as sensitivity and selectivity[11]. Due to catalytic oxidation based mechanism of SnO_2 and other materials, the detection of CO in presence of H_2 is extremely difficult. H_2 undergoes oxidation and, thus, these gas sensors have been more

sensitive towards H_2 rather than to CO . In agriculture field, air conditioning system, importance of CO_2 based gas sensors has increased[12].

In the physiological context, ozone (O_3) detection has gained interest[13]. Moreover, these gas sensors should have high value of sensitivity as well as high selectivity due to very low permissible concentration of ozone. In some studies, developing of NO_x sensors has shown via semiconducting metal oxides and organic layers. But, organic layers based sensing devices are less suitable for NO_x detection due to its degradation in comparison to semiconducting metal oxides. Liquid petroleum gas (LPG) has been evidenced to be hazardous due to various explosions caused by leaks. Therefore, good sensors needs to be produced for the detection of LPG[14].

In medical, chemical fields, measurement of dissolved oxygen is extremely important for which electrochemical based oxygen sensors have been displayed as a dominant tool. By developing miniaturized sensors, significant progress has been done by microelectronic fabrication technology. Therefore, with miniaturization, these sensors can be made with lower price. Moreover, due to compact size, these sensors can be used in biomedical field. The fire needs to be detected early before it reaches to its advance level[15]. Additionally, due to large use of synthetic materials, lot of deadly gases are liberated in the early stage of fire and demonstrated to be dangerous. Traditional fire detection sensors only work at higher temperatures. Therefore, these sensors are not effective and do not react in this case due to low temperature in initial stage of fire. These gas sensors react late and cannot reveal the presence of toxic gases in initial stage. During the combustion, the emitted toxic gases are CO_2 , Cl_2 , and SO_2 . However, the content of these gases may be different in the context of combustion of different materials. Therefore, gas sensors which are sensitive to only one of the toxic products of combustion, is not found to be useful. Thus, gas sensing devices for fire alarm should have high value of sensitivity and non-selectivity to the large number of poisonous gases in the fire. Semiconductor-based gas sensors[16] works well for prevention of initial stage of fire and can be established on the basis of their selectivity.

3. Merits of integrated gas sensors

Integration reduces the errors of reproducibility and mismatch among various sensors and also leads to reduction of signal-to-noise (S/N) ratio while processing the transduced signals[17]. Therefore, communication of transduced signals to the processing electronics results in generation

of less noise as a result of availability of signal processing near the sensors themselves. Sensitivity improvements accompanied with integration improvements. However, there are some problems accompanying with integrated micro gas sensors[18]. These are: (i) inconsistent responses of same gases taken over time (ii) mismatch due to discrepancy of the same gas from different sensors, (iii) problem in detecting some gases having low concentration, (iv) low parameter stability due to different environment conditions, (v) poor selectivity which reflects to problem while resolving the generated signal among different gases etc. However, integrated gas sensor development is at peak despite all these shortcomings and there is continuous research on improvement of these gas sensors.

4. Different kinds of gas sensing materials

From past few decades, extensive research has been performed out on metal oxide based gas sensors[19]. Metal oxide based sensors have various merits such as simple device structure, cheaper, compatible in practical applications, and flexibility to a extensive range of reductive or oxidative gases. A lot of active groups have performed research on these types of gas-sensing materials. In addition to this, there are quite a few technological problems which need to be solved. These oxide based gas sensors has not been produced in thin film based technology. These are mostly produced in sintered block or thick film type form. Moreover, these materials have been tried to fabricate in thin film form for gas-sensing applications. However, despite all efforts, stable thin films at high temperatures have not been produced yet[20]. In order to enhance thermal stability of these films, different suitable techniques need to be introduced. Table 1 shows the literature review of performance of various materials used to detect several gases. These materials are synthesized in different forms such as nanocomposites, nanoparticles, microfibers etc. Thus, it is important to optimize the efficiency of these gas sensors for sustainable development. Further, these gas sensors can be classified into several categories. Further, we have reviewed the application of these various oxide based gas sensors[21].

Table 1. Comparison of detection performance of several gases using different materials.

S. No.	Gas sensor materials	Detection of Gaseous species	Operating temperature (°C)	Form of material	Reference
1.	Ta ₂ O ₅ -SnO ₂	CO	50	Homo-junction nanocomposites	[22]
2.	V ₂ O ₅	NO ₂	150	Nanostructures	[23]
3.	WO ₃ -SnO ₂	Triethylamine	220	Nanoparticles	[24]
4.	SnO ₂	Triethylamine	270	Microfibers	[25]
5.	Ln ₂ O ₃	General	300	Microtubes	[26]

4.1. Aluminum-Oxide based sensors

Aluminum based sensors are excellent candidate for the humidity detection purpose[27]. However, these sensors may degrade its sensitiveness in high humidity conditions. Therefore, care has to be taken while operating these sensors in high humidity conditions. These sensors operate quite efficiently at room temperature conditions.

4.2. Cadmium-oxide gas sensors

Among, Cadmium oxide gas sensors, CdO is used to detect the presence of cetone in bloods in the temperature range from 300-450°C which can determine whether person is diabetic or not[28].

4.3. Chromium-oxide based gas sensors

Among, Cr-oxide based gas sensors[16]; Cr₂O₃ phase is sensitively efficient to sense certain gases i.e. H₂, CO₂, and O₂ gases at 450°C.

4.4. Cobalt-oxide based gas sensors

Among, Cobalt oxide based gas sensor, CoO is the most stable phase. Cobalt oxide based gas sensors are found sensitive towards detection of NH₃[29].

4.5. Copper-oxide based gas sensors

Among large number of copper oxide based gas sensor, CuO is found to be effective in detecting H₂, O₂, ethanol etc[30].

4.6. Iron-oxide based gas sensors

For Fe, there are three stable oxide phases i.e. Fe_xO , Fe_3O_4 , and Fe_2O_3 . Fe_2O_3 material is able to trace the gases such as CO , CO_2 , CH_4 , O_2 , and H_2 in the operating range of 450-1075°C[31].

4.7. Molybdenum based gas sensors

Among Molybdenum based gas sensors, MoO_3 phase is famous for gas sensing applications. This phase of molybdenum is highly sensitive to the detection of NH_3 and NO_2 gases in temperature range from 200-450 °C. However, surface instability is quite concern issue for the molybdenum based oxides. Moreover, addition of Ti layer in MoO_3 surface exhibit better sensing properties for NH_3 in comparison to bare MoO_3 based gas sensors.

4.8. Nickel-oxide based gas sensors

In Nickel-oxide based materials, NiO phase is able to detect CH_4 in the temperature range 300-640 °C when doped with noble metal.

Thus, there are large numbers of oxide based gas sensors which can be used to detect the gases depending upon our requirement.

5. Conclusions

In this chapter, various gas sensors comprising of different materials have been described. Gas sensors are used to detect presence of large number of toxic gases which can be used to protect environmental and other fetal happenings. Oxide based gas sensors shows the high selectivity and sensitivity of certain gases. Currently, Solid state based gas sensors have been used for several application in the field of medical, chemical, environmental protection, humidity detection etc. Additionally, integrated sensors are found to be helpful in reduction of reproducibility and mismatch errors among sensors. Finally, some high performance gas sensors are reviewed. Thus, to have sustainable development, it is important to fabricate high performance gas sensors. In the end, various oxide based gas sensors are described with their potential applications.

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