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A Survey on Smart Sensors Drivers and Gas Detection Technologies

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Review Article
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Abstract

Nowadays, technologies for sensing the presence of gases are being extensively studied and explored for identification or recognition at room or any other temperature. Advanced sensor machinery for gas detection is used in various fields such as greenhouse gas monitoring, chemoresistive, and optical gas sensor, etc. Based on indigenous technical advances and literature investigations, new developments and improvements in sensors proposed to meet the increasing demand of rigorous performance in forthcoming varied applications, are described in the present study. This review paper provides descriptions, evaluation, comparison and evolutions in prevailing pioneering technologies for gas sensing. Various sensing technologies are given, based on the variation of electrical and other properties. Furthermore, this paper focuses on various metal oxides and electrical properties for performance indicators to compare different sensing technologies analyze the factors, temperature, or room temperature several corresponding improved approaches.

Keywords: Greenhouse; Chemoresistiv; Recent Developments; Sensing Technologies; Factors

Abbreviations: WPD: Windows Portable Devices; UMDF: User Mode Driver Framework; SMO: Semiconductor Metal Oxide; PCB: Printed Circuit Board; OSHA: Occupational Safety and Health Administration; MRI: Magnetic resonance imaging; TEM: Transmission Electron Microscope; R0: Initial Resistance; Rf: Period of Resistance.

Introduction

Recently, researches show that one-dimensional (1D) and two-dimensional (2D) nanostructure semiconducting oxides have several advantages concerning traditional thin-film (prepared by thermal evaporation, spin coater, spray pyrolysis methods etc.) and thick-film (prepared by doctor blade method) sensors such as high surface-to-volume ratio, dimensions comparable to the extension of surface charge region. This segment devoid of majority charge carriers penetrates to a nearly small number of debyes inside the bulk material [1-3]. Although smart sensing has played a role in life and production, it should be emphasized that there are still many challenges in the development of smart gas sensing corresponding to the various stages of technology [4].

During the past sixty years, different studies have established various branches of gas sensing technology. Important things in the present scenario include the investigation of diverse types of sensors, research about sensing principles, and fabrication techniques [5-9]. The sensor resistance is usually used as a measure of sensor response, which detects the current or voltage changes. World-level research on smart gas sensing technology is a combination of a gas sensor array and pattern recognition method to detect, analyze, and quantify mixed gases, which can achieve high measurement accuracy of sensitivity of response and recovery time and get smarter conclusions [10-14]. The developments in sensor technology are consequently based on permanent technical progress in various fields.

The sensors which are the heart of instrumentation systems are 'smart' in nature now. A 'smart sensor' consists of the identifier/detecting component on a chip along with allied microelectronics for conditionally affecting signal etc. [15,16]. One of the important features regarding the system of smart sensors facilitates one to provide vital data to the handler with enhanced steadfastness and veracity. Smart sensors normally have their components integrated onto the same printed circuit board (PCB) [17, 18-66]. This level of integration improves both reliability and performance while reducing production testing costs.

This review paper summarizes the relevant researches published and provides a comprehensive study on smart gas sensing technology. Therefore, a lot of research is ongoing to develop new sensing materials and to improve and optimize various elements of established gas sensor types. A fundamental thing is a particular focus devoted to the preparation of gas sensors, technology, drivers and, the preparation of nanomaterials. The applications are discussed in much more detail in the following article.

Requirements of Gas Sensors

Requirements on Oxygen Safety Sensors

Oxygen measuring/monitoring gadgets are proposed to be connected in animals and/or test sites or laboratories to uninterruptedly measure oxygen levels. Too much presence of oxygen or rare case of oxygen at the workplace can at times be dangerous so it becomes important to continuously check the levels of oxygen. Also, the density of air, 1,354 kg/m3, is the same as that of oxygen. The minimum and the maximum safe level or concentration of oxygen specified by the Occupational Safety and Health Administration (OSHA) is 19.5%, and 23.5% respectively. Oximeters or Oxygen measuring tools are desired at a few locations under the OSHA confined space regulation.

Some of the typical places where trampled gases are observed that potentially create an oxygen-deficient atmosphere are as follows [19-25]:

- Magnetic resonance imaging (MRI) rooms (or magnet rooms)
- Transmission Electron Microscope (TEM) rooms
- Freezer farms

The various requirements can be briefed as follows:

- reliable response with sufficient accuracy and sensitivity (20.7% at average humidity level)
- change in the signal to noise ratio
- robustness including low sensitivity to environmental parameters such as:
  - temperature (-20 to 60 °C (safety)
  - pressure below the 60 kPa (8.7 PSI)
  - relative humidity (21 to 100 %),
- gas flow rate independence,
- High accuracy
- Response time <8 sec (63%)
- Lower fouling sensitivity
- Measures absolute oxygen concentrations without repeated calibrations
- Better long-term stability
- Less affected by pressure
- Not freezing sensitive
- Small size

Requirements for NH_3 Safety Sensors

Ammonia, a naturally occurring gas, exists although the atmosphere. Devices that sense Ammonia along with accompanying detecting instruments are vital in estimating the ecological conditions at locations that use anhydrous ammonia. Formerly, relatively low concentrations, of low-ppb to sub-ppb levels, were sufficiently higher [26-28]. Ammonia sensors include a long-life version commonly used for process leak detection. The purpose of these detectors is to sense and divulge the occurrence of ammonia in the human environment or property defences and for apparatus control. Applications of sensing devices for ammonia are swiftly improvising with enhanced refrigeration controls [29,30]. Demonstrates the brief statement of ammonia (NH_3) sensor exposure effects on human health at various concentrations (ppm) (Table 1).

S. No.	Ammonia Vapor Concentration (ppm)	Effects	Remarks	Reference
1	05-Oct	odour threshold	a very pungent odour, detectable by humans at concentrations	[31]
2	25	noticeable odour	irritation and general symptoms	[32]
3	35-50	odourous	moderate irritation to the eyes, throat, noseand chest	[33]
4	100	strong	Any exposure period	[34]
5	150	very strong odour	50% of Immediately Dangerous to Life & Health concentration	[35]
6	200	very strong odour	disagreeable odour and respiratory distress	[36]
7	300	Over powering odour	Immediately Dangerous to Life & Health	[37]
8	400	major throat irritation	Ordinarily, no serious results following short exposures	[38]
9	500	Throat irritation	cold or nasal dryness	[39]
10	1000	immediate coughing	nasal dryness and lungs	[40]

Table 1: Summary of anhydrous ammonia sensor exposure effects.

Requirements on NO_2 Safety Sensors

Nitrogen dioxide is almost imperceptible to humans. Depending on the temperature, nitrogen dioxide can appear as a colourless solid, a yellow liquid or a reddish-brown gas. It is heavier than air, as well as being acidic, corrosive and oxidizing. Annual mean concentrations of NO_2 are highest in urban environments and around major highways [41]. Nitrogen dioxide (NO_2), one of the harmful gases to human health, is widespread in surrounding environments. These gas-based sensors are produced to the best quality ethics, giving products that are exceedingly accurate as well as sensitive for the air quality and gas safety also. Nitrogen dioxide sensor technology provides reliable sensors for use in several high accuracy applications. NO_2 sensing strong signal levels combined with low ppb (parts per billion) in addition to an operational range of 20ppm (parts per million) [42-56]. Shows the NO_2 toxicity level and related health symptoms at high to low concentrations (ppm to ppb) (Table 2).

Sensitivity to environmental parameters at low ppm of NO_2 such as [43]:

- Ttemperature (-20 to 50°C (safety)
- Operating pressure 1013 hPa±10%
- Operating humidity (15~90 % RH),
  - Gas flow rate independence,
  - Highly accuracy
  - Response time <25 sec
  - High sensitivity
  - Better high stability

S. No.	NO_2 Level in Air	Toxic Symptoms	Reference
1	5 ppm	Chronic bronchitis, emphysema	[44]
2	5 ppm	Nose, Eye and upper respirational exasperation	
3	5 ppm	Chronic bronchitis, emphysema	
4	1 ppm	Mild headache	[45]
5	1 ppm	Lower respirational irritation, Acute pulmonic oedema; (cough, dyspnea)	
6	1 ppm	Eye, nose, and upper respiratory irritation	
7	0.2 ppm	Lower respiratory irritation	[46]

Table 2: Nitrogen dioxide, associated Health Indicators and Toxicity levels.

Sensor Technology Drivers

In recent times many countries industry is experiencing shorter innovation cycles, the growing technical complexity of their products, and increased costs in conducting and commercializing research and development. Active trends have important implications for sensor development technology. Semiconductor metal oxide (SMO) play role in sensor technology developments to specific targeted applications. According to the technology business development manager, sensor fusion leads to smarter and better applications, specifically in the field of autonomous movement. Drivers of sensing hardware are accomplished by the Windows Portable Devices (WPD) driver archetypal, that uses on the Windows User Mode Driver Framework (UMDF) [47].

The commission acknowledged three basic sensing drivers to develop new and upgraded sensors and associated constituents [48-66]:

- Economic (improved, quicker, cheaper);
- Regulatory, (for example: environmental and safety monitors, automotive emissions control);
- Unique government requirements, typified by Department of Defence or Department of Energy needs in energy, the environment, and defence.

Smart Gas Sensor setup and calculation

Smart gas sensing technology is a combination of a gas sensor array and pattern recognition method to detect, analyze, and quantify mixed gases or single gas, which can achieve high measurement accuracy and get fast response and recovery time with accuracy [4]. Smart technology is a promising research advanced technique that will broaden the development of a wide range of next-generation smart gas sensor applications aimed at improving the safety (for humans) and leakage or flow control of existing and future safety systems.

The working principle of metal oxide requires divergences in the depletion layer at the boundaries of grain when reducing or oxidizing gases are present. This gives modulations in the energy barriers allowing free charge carriers to cross the barrier and flow [49]. Shows the blocks diagram of the gas sensor setup for different metal oxides/nanomaterials thin film (Figure 1).

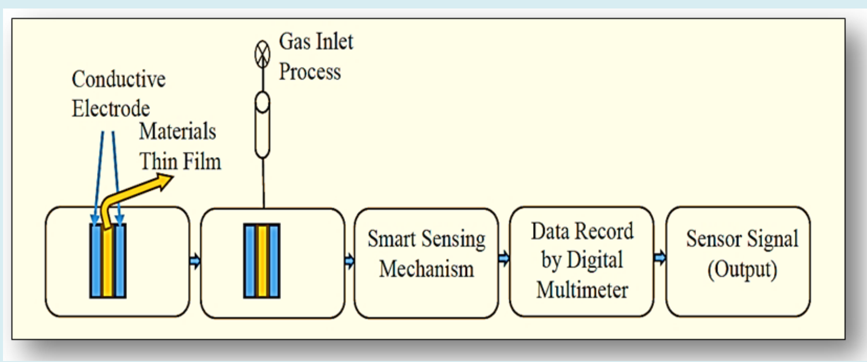

Figure 1: Blocks of gas sensor data analysis setup for different nanomaterials thin film [49].

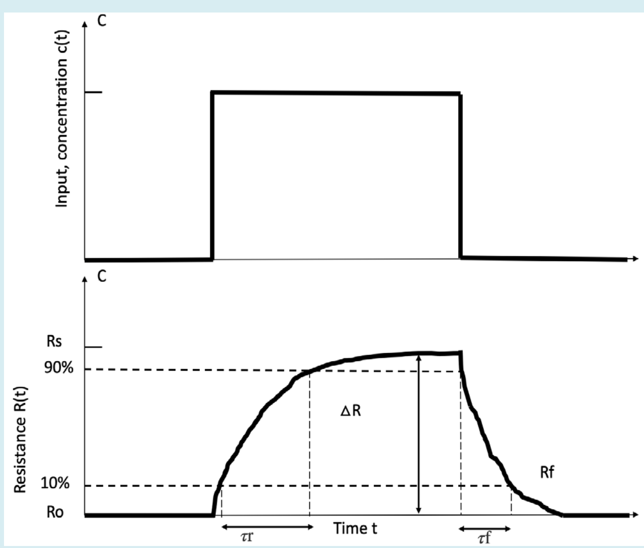

Figure 2: Typical response of a Chemical gas sensor [50].

Shows two standard parameters from the baseline manipulation technique: $4R_s$ and $4R_f$ (Figure 2).

- R_0: the initial resistance of a sensor calculated as the average value of its resistance during the first minute of a measurement.
- R_s: the steady-state resistance calculated as the average value during the latest minute of a measurement.
- R_f: 10% of response sensor at the end of the acquisition period.

ΔRs means the resistance of the sensor rises from Ro to Rs, which provides information about the response time t (second) and ΔRf shows the resistance of sensor rises from Rf to Ro providing the recovery time t for a fall time (second). The standard procedure is to select the steady-state response means saturation state of each sensor as shown in (Figure 2). The fast response rate and recovery rate of Metal oxide materials to the gas mixture or single gas concentration depend upon the properties of the materials. Gas response sensitivity calculates from the initial resistance (R0) of a sensor and the end of the acquisition period of resistance (Rf).

Rs and Rf (Figure 2) whose expressions are given by [50]:

ΔRs
ΔRf

Trends in Gas Sensor Development

The presence of various gases for e.g. toxic, flammable and combustible gases could be identified using sensor devices. These devices were consumed by abundant industries such as power stations, transportation, chemicals, food and beverage and metals. Sensors are based on tested technology, new procedures of production are empowering lesser, lower power, and more choosy sensors. In addition to actual size and length scales, the surface and bulk properties and differences between those properties play a noteworthy role in gas sensing applications [49]. Advanced detection techniques providing mainly surface information, would provide a more detailed picture and a better understanding of gas sensing properties [50]. Show the four classes of classified sensors with different parameters, the first-class containing the CNT and MOS, the second class containing polymer chemiresistor and ChemFET, and the third class containing Piezoelectric and SPR, and last fourth class which contains conventional chromatography and optical spectroscopy (Table 3).

Sensors								
	Class 1		Class 2		Class 3		Class 4	
Parameters	CNT	MOS	Polymer Chemiresistor	Chem FET	Piezo electric (SAW)	SPR	Chromatography	Emission Spectroscopy
Selectivity	+	+	+	+	-	- -	++	++
Sensitivity	+	+	+	+	+	+	+	+
Power saving	+	-	-	+	+	++	+	+
Low cost	+	+	+	+	+	- -	- -	- -
Noise efficiency	+	-	- -	+	+	+	+	+
Size miniaturization	+++	++	++	+	+	+	-	-
High response time	++	+	+	+	+	+	- -	+
CNT- Carbon Nanotubes, MOS- Metal Oxide Semiconductor, Chem FET- Field Effect Transistor with a solid electrolyte as the gate material, SAW- Surface Acoustic Wave, SPR- Surface Plasmon Resonance								

Note: The negative (-) sign indicates a disadvantage and the positive (+) one indicate an advantage for the sensor at the corresponding parameter.

Table 3: Discussion of different types of sensor parameters with different materials [54,55].

Conclusions

In the present review article, the authors have discus with the major types of gas sensing technologies mentioning some of the developments in their field of research. The recent trends are focusing on investigating advanced technologies and approaches in addition to improving the conventional leading-edge sensor technologies. Research on new semiconductor metal oxide sensing materials, expansion of new sensing machinery, and diminishment of sensor podia yielding equipment with improved delivering output at a decreased cost are also presented. The development of the most popular sensor models, techniques, and approaches, which are widely used to estimate advanced technology and the response of various gas sensors.

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