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# A review on p-n heterojunction based nano-composites for Gas sensing applications

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## Abstract

Metal oxide based nanocomposite gas sensor is a device that converts the information of a gas or vapor analyte species into electrical signals using various detection principles. Change in electrical resistance/absorbance occurs when sensing material is exposed to the particular gas which is to be exposed. In order to enhance the sensitivity and selectivity of sensing material various metal dopants and different types of heterojunction can be formed with the combination of organic and inorganic materials. Due to the modification with the formation of p-n and n-n heterostructures by the inclusion of dopants and different types of nanomaterials, stability and reversibility of sensing material can be enhanced and also the response and recovery time of the material can be reduced. Surface morphology of different dimentional materials (0D, 1D, 2D, 3D etc) plays a vital role for the absorption and desorption of gas analyte. Sensing material should have large number of active sites for interaction of large analyte molecules. Morphology of synthesized materials can be explained through SEM, TEM and AFM. Material should have large surface to volume ratio and many more active sites for enhanced sensitivity and selectivity. Organic/Inorganic nanocomposite materials are reliable sensors for gas molecules at room temperature for a broad range of gases.

Keywords: Gas Sensors; Nanocomposites; p-n heterojunction; Nanotechnology; Sensitivity.

## INTRODUCTION

In recent years, nanotechnology leads to the development of gas sensors made up of metal oxide and composites due to the excellent sensing sensitivity at room temperature, high response for various target gases, high stability, and low cost (Sowmya et al. 2021). Gas sensors can be used in detection of leakage and poisonous gas emissions from various industries, detection environmental air quality monitoring, biosensors for diagnosing various diseases and in food industry etc. The reliable sensing material should have large surface area to volume ratio, high aspect ratio, high porosity etc (Sharma et al. 2017). The characteristic property of gas sensors varies with temperature and its resistance values get changed which is then recorded when there are changes in voltage/current as a measure of its response and recovery value. Larger the diffusion of gas molecules, more will be the sensitivity of gas sensors i.e. sensitivity depends on the distribution of charges on the surface of gas sensing material. Pristine metal oxide based gas sensors have high sensitivity, selectivity and high response with less recovery time but they require high temperature to operate (~250˚C) i.e. they have high power consumption (Xu et al. 2011). High temperature operation is not suitable for sensing devices due to danger of explosions. Different types of material composition can be used for detection of various oxidising and reducing gases. Different polymers with metal oxides (PANI/$SnO_2$) nanocomposites show synergistic effect for the detection of various gas analytes and works at room temperature (Sharma et al., 2016). The sensing mechanism of PANI/$SnO_2$ nanocomposites for hydrogen gas (Sharma et al. 2015), ammonia vapors, HCl vapors can be explained on the basis of existence of p-n heterojunction formed by p-type (PANI) and n-type ($SnO_2$) semiconductors. In this paper review of sensing mechanism of hybrid materials is explained.

## EXPERIMENTAL METHODS

Metal oxide can be synthesized by various methods through solution route techniques which include Sol–gel method, Micro emulsion method, Laser ablation method, Chemical vapor based methods etc. The oxides $In_2O_3$, $WO_3$, $TiO_2$, ZnO, $SnO_2$ etc. shows reliable gas response for various oxidising and reducing gases (such as hydrogen).

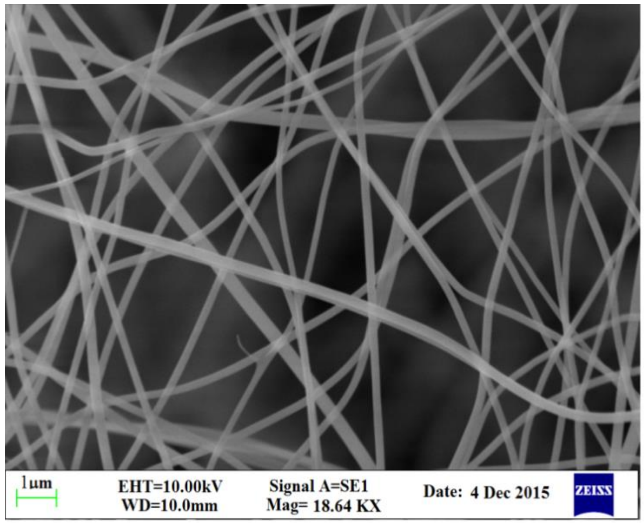


**Figure1**: SEM Image of Nanofibers of metal oxide

1D material can be synthesized by electrospinning method, chemical/physical vapour deposition, electrochemical anodization and electro-deposition, etc. **Figure1**. Shows the SEM image of nanofibers fabricated by Electrospinning technique and calcination procedure (Li et al. 2004).

The polymer can be synthesized by in situ chemical oxidative polymerization techniques and composites can be prepared by facile in-situ polymerization dip-coating technique (Gupta et al. 2006).

## FUNDAMENTALS OF GAS SENSORS

Change in resistance when exposed to target gas is the basic principal of metal oxide based gas sensors. The characteristics of gas sensors are determined by sensitivity, selectivity, reversibility, detection limit, response time and recovery time. The sensitivity and selectivity is also determined by adsorptive capacity. Gas Sensing set up consists of a sample chamber, sample holder, sensing element, thermocouple, multimeter, electrodes etc. It also consists with a DC power supply and data can be obtained on the screen of a computer in the form of excel sheet in the form of Resistance Vs Time. Through this data we can calculate sensitivity of sensing material, response and recovery time of element with respect to target gas. The software works on sensing data can be developed in visual basic. **Figure 2.** Shows the test software front panel screen.

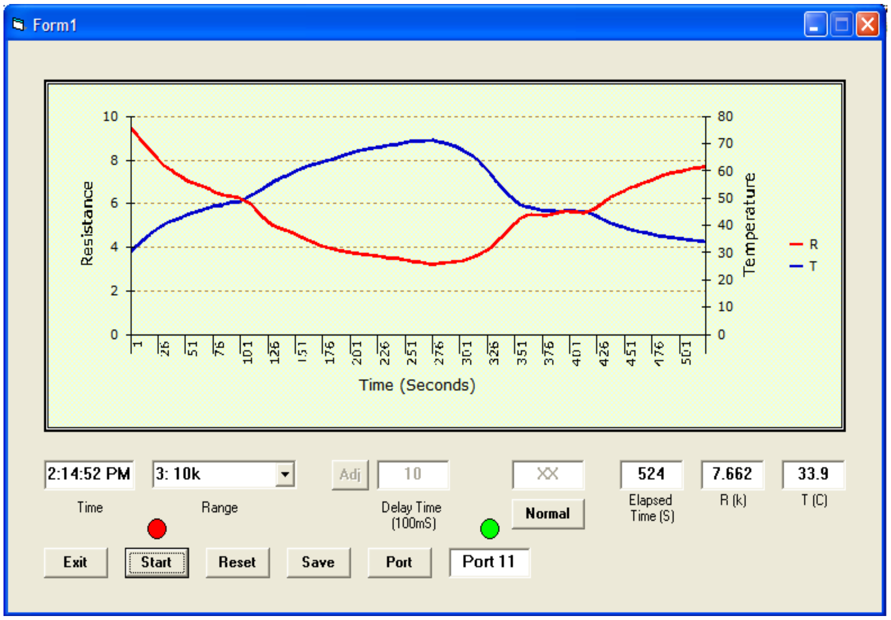


**Figure 2:** GUI of the sensor resistance measurement instrument

The sensitivity factor (S) and Response (R) was calculated with the help of equation (1) & (2).

$$\text{Sensitivity Factor (S)} = \frac{R_0 - R_g}{R_g} * 100 \qquad \text{--------------------- (1)}$$

$$\text{Response (R)} = \frac{R_0}{R_g} \qquad \text{-------------------- (2)}$$

## MECHANISM OF GAS SENSING

Formation of p/n heterojunctions in the nanocomposites leading to much enhanced sensitivity and response magnitude. Hetero-p-n-junction (as shown in **Figure 3**) between organic/inorganic composites increased the sensor resistance which may lead to enhance sensing characteristics. Therefore, composite samples showed superior gas sensor performance. When n-type sensing material is surrounded by p-type material, it makes p–n junction like formation (Sharma et al. 2015).

Locally in composite film and between them a depletion region is created which polarizes the gas analytes and provides charge carriers to the sensing materials and thus electrical characteristics of material changed which is responsible to enhance sensing characteristics (Nasirian et al. 2015).

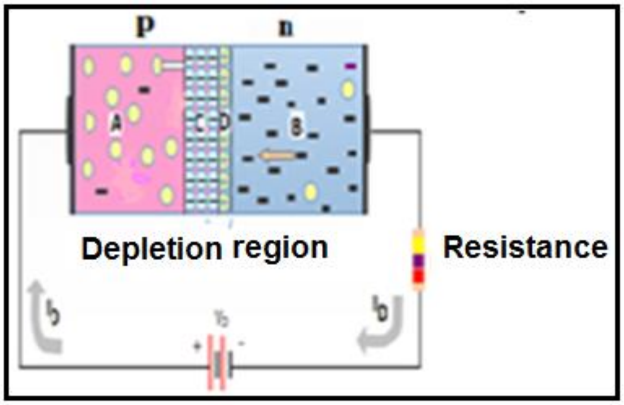


**Figure 3:** P-N junction formation

## APPLICATIONS OF GAS SENSORS

Applications of gas sensors involved growing demand for environmental safety and energy preservation. Gas sensors have industrial, automotive, aerospace and also applications in household etc. to ensure a safer environment. Gas sensors are mainly intended to detect and monitor the gases for environmental concern. Carbon dioxide sensors are essential for detecting leakage during combustion of hydrocarbons. Chemical sensors can be used in aerospace and used in launch vehicle emission monitoring, leak detection and fire detection. They can be used in industries for leak detection of hydrogen and various hazardous and poisonous gases detection into the atmosphere.

## CONCLUSION

Nanocomposite based gas sensors can be synthesized by chemical oxidative polymerization technique and solution route technique. Chemical gas sensor performance features such as sensitivity, selectivity, time response, stability, durability, reproducibility, and reversibility are largely influenced by the properties of the sensing materials used. The synthesized sensing materials can be characterized by SEM, TEM etc. for morphology and topology of sample. The composite sensing material can be used for sensing various oxidising (such as HCl) and reducing gases (such as ammonia) (Kondawar et al. 2012). The sensing mechanism can be explained on the basis of p-n junction formed between nanocomposites. A higher specific surface of a sensing material leads to a higher sensor sensitivity, therefore many techniques have been adopted to increase the specific surface of sensing films with fine structures. Due to its room temperature operation, the gas sensor is promising for environmental applications. In future sensitivity of the synthesized sensing materials can be enhanced.

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