

# Semiconductor Metal Oxide Nanoparticles: A Review for the Potential of H<sub>2</sub>S Gas Sensor Application

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## Abstract

In modern world, gas sensors play important role in many fields of technology used for air pollution, breath analysis, public safety and many others. Gas sensor based semiconductor metal oxide is mostly used in these applications because of low cost, ease-to-use, high sensitivity and lower power consumption. This paper gives an overview about the semiconductor metal oxide and reviews why using it as sensing of gases in electrical applications and then it addresses to the work mechanism of a sensor to sensing H<sub>2</sub>S gas.

## Abbreviations

MOS	Metal Oxide Semiconductor
NPs	Nanoparticles
MO	Metal oxide
ZnO	Zinc oxide
H <sub>2</sub> S	Hydrogen sulphide

## 1. Introduction

The applications based on gas sensor technology play an important role in our life, such as the detection of toxic gas, the quality of air and control of environmental [1-8].

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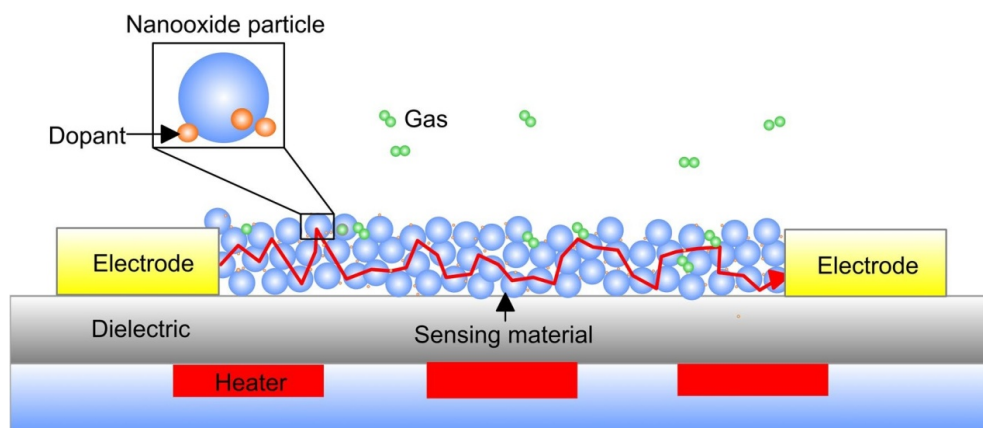
Keywords and phrases: gas sensor, MOS, nanoparticles, H<sub>2</sub>S.

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Many types of sensors have been used to detection of gas but the type that based on resistivity is most used because the low cost prepared and ease operation [9-16]. The first commercial oxide-based gas sensor was used in 1963 by Taguchi to detection H<sub>2</sub>S gas using ZnO. After that, many efforts were made to improve of properties such as the selectivity, stability and sensitivity. Semiconducting (MO) - based gas sensor has attracted the researchers comparing with the conventional techniques because it advantages such as low cost and sensitivity and fast responsible and detection. Because of the electronic unique properties of semiconductor metal oxide nanoparticles, it used in various applications such as gas sensor, lithium battery and solar cell. Many semiconductor metal oxides were used as gas sensor because have electric properties such as In<sub>2</sub>O<sub>3</sub>, TiO<sub>2</sub> and SnO<sub>2</sub>. In spite of advantages, there are many disadvantages that (MOS) appear like higher energy consumption. The appearance of nanotechnology allowed great progress that has been made in the field of sensing because of the unique properties that nanomaterial has such as high surface area to volume, surface active site and very high surface reactivity [17, 18]. This review aimed to study the mechanisms of gas sensing using semiconductor metal oxide (MOS) and appear the effect of temperature and role of particle size in efficiency of sensing.

## **2. System of Gas Sensor and Mechanism**

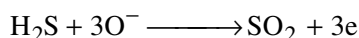
The gas sensor contains sensing film which changes the resistance upon exposure of gas, two conducting electrodes that measure the resistance and heater to control and to get optimum working temperature as shown in Figure 1. The electric conductivity of sensor changes upon explore to gas while the receptor and transducer functions depend on the interaction between the gas and solid gas sensor and the structure of metal oxide respectively. The mechanism of gas sensing realized by changing the resistance as results from interaction the target gas with sensor, number of surface active sites and adsorption the species of O<sub>2</sub> that increase the active sites of the surface [19]. Many factors play important role on the affectivity of surface conductivity specially the surface stoichiometry due to the vacancies of O<sub>2</sub> increased the conductivity while the adsorbed ions less or decreased it. At MO vacancies, O<sub>2</sub> or NO<sub>2</sub> adsorbed and this causes the flow out of the electrons of conduction band and decrease the surface conductivity while H<sub>2</sub> or CO in atmosphere react with adsorbed O<sub>2</sub> and release electron and increasing the conductance.



**Figure 1.** Conductometric gas sensing device [19].

### 3. Detection of H<sub>2</sub>S Gas by MO

The mechanism in conductometric for sensing gas is based on the resistance as a result of interaction between target gas and sensor. In air, large electronegativity is found back to oxygen that adsorbed on the surface of semiconductor gas sensor and abstract electron from conduction band of metal oxide and formed on the surface oxygen ions  $O_2^-$ ,  $O^-$ . This trapping of electron causes increasing the resistance in n-type of gas sensor and decreasing in p-type [20]. The abstraction of electrons from the outer surface of metal oxide results accumulation layer in p-type and electron-depleted layer in the n-type [21]. The electron concentration in depleting layer low and this causes decreasing the resistance in layer compared with core layer in n-type MO while, the resistance is lower in accumulation layer in p-type comparing with core layer due to the holes are in the majority in this type. When exposed the sensor of MO with target gas, the gas reacts with oxygen ions absorbed on the surface and causes to release of electrons and back to MO and the processes can be expressed by the equation:



The releasing of electrons to MO decreasing the width of depleting and accumulation layers and this causes increasing and decreasing of the resistance of p- and n-type, respectively. X-ray photoelectron microscopy (XPS) used as a characterizing tool to understand the mechanism of sensing H<sub>2</sub>S on the sensor. Many researchers used this tool

to characterize or demonstrate the interaction between the target gas and the surface of sensor. Vishal reported a large shift in the position of peak for O 1s after exposing to H<sub>2</sub>S gas and this indicates occurring interaction between oxygen site and target gas as well as, two bending energy appear at (160eV) and (165.3 eV) back to sulfide and sulfite respectively, characterize to conversion of Fe<sub>2</sub>O<sub>3</sub> to Fe<sub>2</sub>S<sub>3</sub> then decomposition of FeS and FeS<sub>2</sub>.

#### **4. The Effect of Temperature**

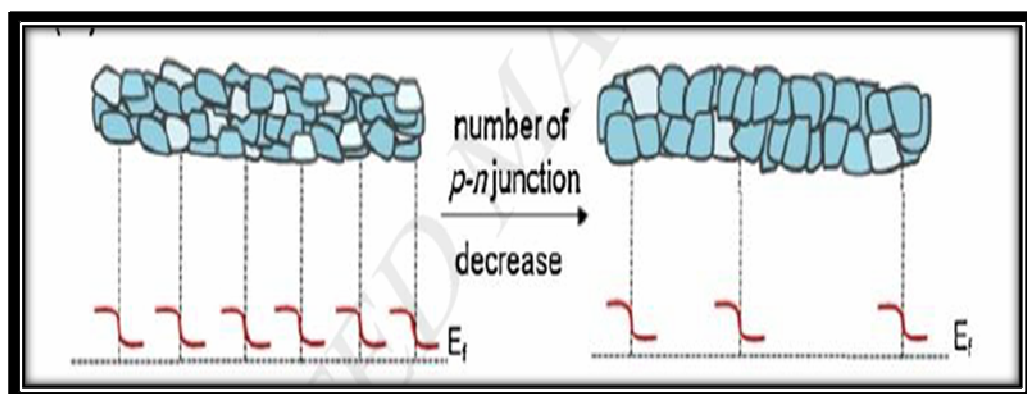
The absorption reaction and change in the temperature of sensor continuously work on the changing of conductance. Thereby the optimum temperatures are directly related to release of electrons to conduction band and increasing the conductance [22]. To control the reaction rate, heating gas sensor used [23]. At low temperature, the response of sensor is controlled by the chemical reaction speed while the speed of molecules diffusion plays the main role at high temperature. These two processes become equal or equilibrium at optimum temperature. The heating in conductometric sensor is direct or indirect but the indirect heating is preferable to prevent or lack of interference with sensor layer. The system of MOS-based gas sensing works at high temperature with range 100-400C and this causes to reduce the stability, life time and sensitive of sensing because the growth of metal oxide grains [24-27]. Some sensors fabricate using semiconductor polymer work it at room temperature but it affects by humidity and also causes the poor sensitive [28]. The strategies were ongoing to improve the efficiency and selective of sensor by making composite sensor or functionalization the surface by heterogeneous oxide. In spite of all these efforts but remain the high temperature and humidity are the main problems. For this, the challenge in my field is to prepare sensor work at room temperature with humidity and high selective and response for sensing gas.

**Table 1.** Shows the using many metal oxides with different size and forms working at room temperature.

Materials	Structure	Gas	Conc.	Sensitivity	Response time
SnO <sub>2</sub>	Nanocrystalline tubes	NO <sub>2</sub>	9.7ppb	16.1	20s
SnO <sub>2</sub>	Nanowire	CO	20ppm	4	
CuO	Nanosheet	H <sub>2</sub> S	200ppb	5.01	400s
NiO	nanowire	NH <sub>3</sub>	50ppm	0.19	36s
LaFeO <sub>3</sub>	nanocube	NO <sub>2</sub>	1ppm	0.29	24s
CuO/SnO <sub>2</sub>	nanorode	H <sub>2</sub> S	30ppm	4.8	2.5s

## 5. Role of Particle Size

As a general base, decreasing the size of grain and particles causes increasing the surface area of oxide [29-42] for adsorbing the gas molecules and this leads to higher response of the sensor. As well as decreasing of grain exposes the surface to depletion of electrons during exposing the sensor for air. Additionally, as shown in Figure 2, the size of particles plays main role in the sensing capability of heterogeneous MO depending on the number of n-p junctions. With small particles the number are increased and this causes increase the total resistance compared with large particles and as a result increasing the capability of sensor.



**Figure 2.** Effect of injection number on sensing capability.

## 6. Conclusion

This paper summarized and demonstrated the importance of using semiconductor metal oxide nanoparticles as a gas sensor specially H<sub>2</sub>S because of the intrinsic properties that back to high surface reaction activity and low cost for using at room temperature. The general mechanism of sensing depended on the number of O<sub>2</sub> vacancies and absorption ions on the surface of sensor. The XPS results for detection H<sub>2</sub>S by using Fe<sub>2</sub>O<sub>3</sub> as sensing showed new energy band during sensing assigned to Fe<sub>2</sub>S<sub>3</sub> and FeS<sub>2</sub> and this causes the activity of metal oxide for sensor H<sub>2</sub>S gas. The studies in review appear a great role for increasing or decreasing temperature in activity for sensing. Thereby the optimum temperatures are directly related to release electrons to conduction band and increasing the conductance.

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