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SENSING MECHANISM INVOLVED IN SEMICONDUCTING METAL OXIDE GAS SENSOR: A BRIEF OVERVIEW

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Abstract:* *The present study incorporates gas sensing mechanism for a chemi-resistive type sensor using semiconducting metal oxides (SMO) as sensing material. A detailed view of the interaction process between the target gases and sensor surface has been included with some vital examples of SMO sensor. Furthermore, the advantages and disadvantages of SMO sensor have also been discussed. To explore the sensing mechanism in a better way, different models and influencing factors in gas sensing are included and discussed. So, in this paper we report a focused study on the sensing mechanism of semiconducting metal oxides helpful to explore and correlate different sensing characteristics of the material.

Key words: ***Chemi-resistive sensor, Gas sensing, Gas sensing mechanism, SMO sensor***

1. INTRODUCTION

With the advancement of technology and its vast use in our daily life the environmental pollution (by different hazardous gases) and health harming outcomes (critical diseases like, asthma, lung cancer etc.) associated with it also go on increasing [1 – 4]. To control the above mentioned adverse effects, gas sensor plays an important role by detecting the hazardous gases above critical limit [5]. In the category of gas sensors, chemi-resistive sensors are widely used to detect the gases in different fields [6]. If there is a change in resistance/conductance of a sensing material according to the variation of chemical environment in its nearby then the sensor is termed as chemi-resistive type [7]. These sensors are very sensitive to chemical environment change and thus useful to detect the presence of trace amount of gas. Among various kind of sensing materials semiconducting metal oxides (SMO)are the prime choice for a gas sensing material due to its advantages favourable to sensing [8]. Wide range of gas detection, simplest sensing process, and ease in sensor fabrication are the most common advantages of SMO sensors. Although the high operating temperature associated with the SMO sensor is the principle drawback of the material which enhances the power consumption of the gas detection system.

The change in electronic properties of SMO was first observed by Brattain[9] and Heiland[10] and this feature of SMO was successfully applied for the detection of some hazardous gases for the first time by Seiyama et al. in 1962[11]. The first commercialization of these types of gas sensors was done by Taguchi[12] very soon after Seiyama's report in 1962.The detection technique associated with these SMO sensors plays an important role for the production of commercially viable gas sensors. Adsorption of gases on the surface of sensing material has been considered as the key process of sensing. Although, the actual sensing mechanism of SMO sensors needs to be explored more as some complex processes are involved in this phenomenon, here in this paper we summarises the basicofsensing mechanism related to SMO sensors subject to oxidizing and reducing gases.

2. CHARACTERISTICS FEATURES OF A GAS SENSOR

2.1. *Response:* The response of a sensor towards a particular gas/vapour can be described as the ratio of resistance/conductance of the material in absence (in air) and presence of the gas/vapour. It can be obtained by the equation:

$$R_n = \frac{G_g}{G_a} \text{(for n-type SMO)} \quad (1)$$

$$R_p = \frac{G_a}{G_g} \text{(for p-type SMO)} \quad (2)$$

Where, G_a and G_g are the conductance of the sensing material in presence of air and gas respectively.

2.2.*Response time:* The time taken by the sensor to reach 90% of the total signal change (change in resistance/conductance) in presence of a target gas/vapour is known as response time of the respective sensor. A fast response time is always preferred for commercial gas sensor.

2.3. *Recovery time:* The time taken by the sensing element to recover the 90% of the total signal change (change in resistance/conductance) in presence of air is termed as the recovery time for the sensor. Generally, in SMO sensors recovery time is more than the response time.

2.4. *Repeatability:*If a sensing material can repeat its response curve with almost same value of response (or with negligible deviation) over several times then the sensor is said to be repeatable.

2.5. *Long-term stability:* If the response value of a sensor is stable even after a long time of its use then this feature is called long-term stability.

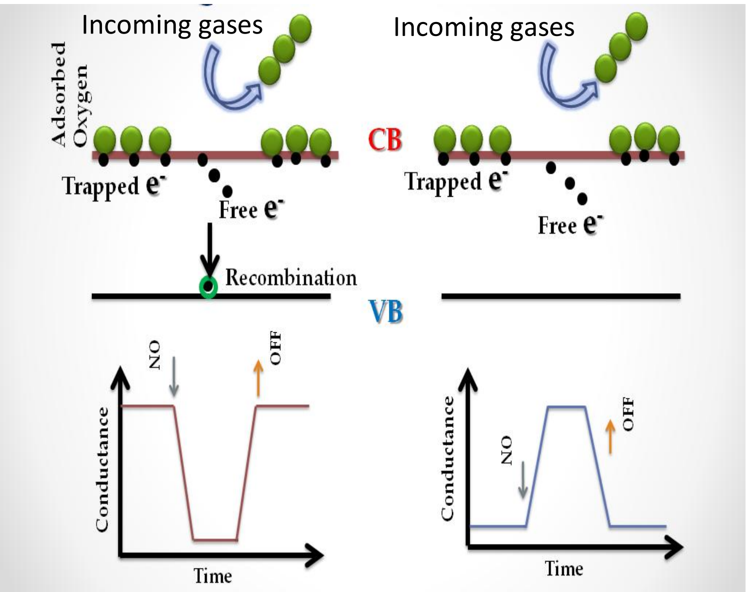
3. SENSING MECHANISM

The sensing mechanism for a chemi-resistive type SMO sensor can be understood by the adsorption and desorption process of ions (oxygen ions) and target gases as well as the interaction between them. The SMO sensors can be divided into two categories depending on the charge carrier concentration as: (i) n-type (ii) p-type

In presence of air, the oxygen molecules are adsorbed on the sensing surface of SMO sensors. There will be a conversion of the oxygen molecules to ions (O^-/O^{2-}) after adsorption as the each adsorbed oxygen trap one electron from the conduction band of the material. In this situation (in presence of air) there must be a moderate value of the conductance of the material. Now in presence of a target gas/vapour, the incoming gasesreact withthe surface adsorbed oxygen ions and remove them (the oxygen ions) from the sensing surface. The removal of the oxygen ions frees the trapped electrons. The free electrons now take part in the conduction process and also in the sensing. So, depending on the type of the MOS materials and also the type of sensed gases (reducing/oxidizing) the conductance of the sensing material either increases or decreases which can be treated as the detection. **Table 1**shows the variation of sensor conductance in presence of reducing/oxidizing gases for different type of MOS materials.

Table 1: Conductance variation of MOS sensor

Type of MOS	Type of Gases	Conductance Change
n-type	Reducing	Increases
n-type	Oxidizing	Decreases
p-type	Reducing	Reduces
p-type	Oxidizing	Increases



p-type MOS n-type MOS

Figure 11 Sensing mechanism for MOS sensors

Figure 1 shows the schematic diagram of the sensing mechanism for n- and p-type MOS sensors subject to reducing gases.

The sequential surface reactions [13-14] involved in the sensing process for reducing gases (R)is given as:

$$O_2(g) \leftrightarrow O_2(ads) \tag{1}$$

$$O_2^-(ads) + e^- \leftrightarrow 2O^- \tag{2}$$

$$R + 2O^- \leftrightarrow RO_2 + 2e^-[\text{Free electron}] \tag{3}$$

So, in presence of reducing (R) gases the conductance of p-type MOS decreases and increases for n-type MOS.

4. CONCLUSION

In summary, the basics of the gas sensing mechanism involved in MOS sensors have been discussed in detail with the example of reducing gases.The reason behind the change in conductance of the sensing material in presence of a particular gas has been outlined with a schematic for better understanding. The adsorption and desorption process of oxygen and incoming gases are included in this report with the reaction kinetics involved. The basic characteristics of a gas sensor have been outlined here to correlate them with the sensing mechanism of MOS sensors. In short, the present study summarises basic concept of sensing mechanism involved in detection of various types of gases using MOS materials.

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