Tin Dioxide – CNT Based Gas Sensor Design

Sayak Mukherjee¹, Anik Mukherjee²

¹University of Calcutta

²Camellia Institute of Technology

Abstract— The SnO₂-CNT based gas sensors can detect harmful gases and also measure their toxic effects on environment as well as living creatures. Monitoring of the sensitivity of the hazardous gases (CO) and volatile organic compound (Acetone) by our SnO₂-CNT based gas sensor are the main goal here. Cross sensitivity of SnO₂-CNT based gas sensor over volatile organic compound (ethyl alcohol) and combustible gases (methane) are also observed here.

Keywords— SnO₂-CNT gas sensors, sensitivity of gas sensors, capacitive effect, Scanning Electron Microscopy (SEM), High energy Sonicator, substrate coating and X-ray diffraction (XRD).

I. INTRODUCTION

Nowadays SnO₂ gas sensors are extensively used in research and development for its higher sensitivity which is mainly based on the high operating temperature. These n-type semi-conductive gas sensor is first introduced in 1962 from then a wide range of toxic gases are monitoring through it. Tin dioxide (SnO₂) is an anisotropic polar crystalline material with tetragonal rutile lattice structure also it shows various properties in bulk and nano dimensions, this oxide materials shows several physical and chemical properties. Tin dioxide obeys to the O=Sn=O structure, among all the elements of Group-IV of the periodic table SnO₂ is always preferable for its conductivity, transparency and particle size. The conductivity of Tin dioxide (SnO₂) is realised by oxygen vacancies, concentration of oxygen vacancies is very difficult to control. Changing the electrical resistance senses the toxic gases. Electrical resistances is depends upon various surface phenomena alike surface impurities, doping concentration, composition of elements and so on. The lattice parameters are $a = 4.737 \text{ \AA}$ and $c = 3.185 \text{ \AA}$ when $a=b$, subsequently the ratio of c/a is 0.673. It is basically 6:3 coordination lattice structure. The band gap of SnO₂ is 3.6 eV, besides that conductivity of the sensor decreases in the presence of oxidizing gases alike O₂ and rises for the reducing gases like CO. The relationship between the gas concentrations with the resistance of SnO₂ is non-linear since resistance of SnO₂ varying always due to variation of the concentration of gas. Performance of a gas sensor depends on its sensitivity, response time, selectivity and chip size.

The size of Tin dioxide particles are in nanometre range so using SnO₂ in gas sensors are reducing the size of sensing device as well as nanocomposite materials are also made with SnO₂ by adding the dopants. The performance of the gas sensor also depends on its selectivity, if it is low then SNR (Signal to Noise Ratio) will be lowered and the targeted gas cannot be sense properly by that sensing device. SnO₂ gas sensors are known for its high sensitivity and low response time because of particle size of this sensing material and operating temperature. The operating temperature is another important parameter, at low temperature when the target gases are introduced the sensor response is insignificant as oxygen is lowered. SnO₂ sensors shows maximum sensing response depends on their operating temperature, up to the critical temperature the sensing responses of Tin dioxide sensors are increases but above that responses will fall again. It is basically depending on absorption and desorption rates of sensors. The range of working temperature is between 25°C -500°C for Tin dioxide sensors..

II. FABRICATION OF THE SENSOR

To prepare SnO₂, at first, 0.2M SnCl₄ .5H₂O (100 mL) aqueous solution was prepared by adding distilled water by high energy sonication. After that, for making a clear solution 2-3 mL of HCL was added by a dropper, then NH₃ solution was slowly added with it until a white precipitate was obtained. This procedure was continued for 1 hour with high sonication. Finally, the precipitate was washed with distilled water 2-3 times and acetone then collected. The cleaned precipitate powder was dried at 100°C vacuum chamber for 12 h to eliminate volatile compounds.

Next to cover SnO₂ with CNT, first high energy Sonication of CTAB (cetyl trimethyl ammonium bromide) and CNT (Carbon Nanotube) was done for 25-30 min with distilled water, where the ratio of CTAB and CNT were 5:1. SnO₂ powder previously mixed with CNT sol and heating 50-60° C also stirring it to make a thick paste. Then Al was coated by the paste. Different composition samples alike SnO₂ +.75 wt% CNT, SnO₂ +0.25 wt % CNT, SnO₂ +2 wt% CNT, SnO₂ +1 wt%, SnO₂ +1.5 wt%, SnO₂ +0.5 wt% were then prepared. Al coated substrates then cut into specific dimensions 3.5mm x 2mm x 0.5mm (approx.) for measurement and polished.

After cleaning the tubes with HCL, distilled water and acetone, finally Au electrode and platinum lead wires were attached with Al substrate. Gold coated Al substrate was cured at 950°C for 1 h.

To prepare the sensor, aluminum substrate was sliced and polished into length ~ 3.5mm, outer diameter ~ 2mm, and thickness ~ 0.5mm and both the edges of the tube and subsequently cleaned with HCl, DI water, IPA and acetone. Then on the aluminum substrates we connected Au and Pt electrode and wires. Next, the sensing powders ($\text{SnO}_2/\text{SnO}_2 + \text{CNT}$) and slight IPA (isopropyl alcohol) were mixed for making thick pastes. These pastes were then coated over substrates (thickness of the coatings was about 50 μm -60 μm). Finally, coated substrate was cured at 350°C for 1 h. Now, both contacts were spot welded by Ni pins fixed on sensor head and inside the tube nichrome heating coil were successfully placed. For monitoring the change in resistivity of the sensing materials two pins of the packaged sensors were connected with a multimeter. For controlling the voltage change the other pins were connected with a dc power supply. Preferably sensors were placed in a closed glass jar, vaporous /liquid gases were finally injected into the closed jar by a syringe.

Here Tin dioxide is used as a semiconducting matrix or a dielectric material and CNT is used as a conductive filter. ϵ_{eff} is symbolically represented the effective dielectric constant, which is defined as,

$$\epsilon_{\text{eff}} = \epsilon_m ((p_c - p)/p_c)^{-q}$$

Where, P_c = percolation threshold (The value of P_c is approx. 0.16 for 3-D lattice structure)

P = Volume concentration

ϵ_m = Dielectric constant of the semiconductor matrix

The value of q is approximately 0.9 for three-dimensional lattice structure

At the percolation threshold the effective dielectric constant increases sharply, this is happened due to separation of metallic filter by semiconducting materials. The depletion region of Tin dioxide semiconductor producing a capacitive effect on conducting CNT's. For detecting the acetone vapor the depletion layer width is being reduced and overall capacitive effect also decreased. For gas absorption heterojunction SnO_2 -CNT metal-semiconductor sensor are being used, by changing the depletion region the barrier height can be controlled.

III. MEASUREMENT AND CHARACTERIZATION OF THE GAS SENSOR

Figure 1 Sensors response to acetone vapor

Figure 2 Amount of CNT vs resistance of the sensor

Figure 3 Acetone concentration vs capacitance change

IV. CONCLUSION

In this research work the sensitivity of CO and acetone are successfully observe by fabricated SnO_2 -CNT based gas sensor. Different types of Tin dioxide-based sensors can be fabricated using this technique and used in various sensing devices. The capacitive effect of SnO_2 -CNT contacts provides no effect on carbon monoxide, moisture, methane and alcohol vapor. Further study is required to innovate the reason behind the phenomena.

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