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SnO₂ Substituted In₂O₃ Thick Films as PPM Level NH₃ Gas Sensors

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Abstract: The SnO₂ and In₂O₃ powder mixed with different ratio and heated at 900⁰C about 5 hrs and then this powder is used to prepared thick films by a screen – printing technique on glass substrate. The NH₃ gas sensing properties, particularly the rate of response of SnO₂-In₂O₃ sensors are studied at room temperature. SEM and EDAX analysis showed that crystallite size is small (86.43 nm) for 65SnO₂-45In₂O₃ composition. The Sensitivity increases drastically as the expose of NH₃ gas for 65SnO₂-45In₂O₃ sample. This sample is found to be better sensing material as regards to other in all respect.

Keywords: Ammonia Gas; SnO₂; In₂O₃; SEM; EDAX.

I. INTRODUCTION

Harmful gases are detected by gas sensors and protect from the harmful gases by fabrication of sensor. Due to modern lifestyle industrial society and older population many chronic diseases are affected . Human diseases are monitoring by the breath are studied in many of the peoples. For analysis breathe that can detect in stomach lung or in other body parts very highly sensitive sensors for particular gases are needed. Strong correlation between exhaled breath and specific diseases many people's studies have been presented . Ammonia gas NH₃ has also been recognized as one of the markers for hepatic or kidney diseases [1]. Ammonia gas (NH₃), a toxic and corrosive indoor air pollutant, is affect to human skin, eye and respiratory system [2, 3]. Various industries and other sources is emitted Ammonia gas (NH₃) into the atmosphere and causes environmental pollution. Considering the danger of ammonia, the application of sensors for detecting leakage from vessels and pipes. Therefore, the development of NH₃ gas sensors are importance to researchers and regulators. For detecting NH₃ gas the use of metal oxide sensors (MOS), such as Tin oxide (SnO₂) and Indium Oxide(In₂O₃), has been develop to detect NH₃ gas, even at low concentrations.

In this paper is focused on the fabrication of Ammonia gas NH₃ sensor based on SnO₂-In₂O₃ annealing route to enhance the NH₃ sensing performance at room temperature. To the best of our knowledge, SnO₂-In₂O₃ gas sensor has not yet been reported in the literature. The fabricated sensors were evaluated systematically in terms of their response, response/recovery times and Sensitivity toward NH₃. The main target of this work is to optimise samples of SnO₂:In₂O₃ and promote the gas sensing performance toward NH₃ at room temperature. The fabricated SnO₂:In₂O₃ gas sensor successfully showed a response several times higher than that of a pure mixed oxide gas sensor.

II. MATERIALS AND METHODS

A. Preparation of Materials and Fabrication Technique

The powders of SnO₂and In₂O₃ were calcinated at 800⁰C in an automatically temperature-controlled muffle furnace for 6 to 7 hrs. The powders of same were crushed in pestle before after the calcination to get the homogeneity in the powders.

The mass percentage of same were mixed in the ratios of 100:00, 70:30, 65:45, 30:70 and 00:100 in acetone to form the homogeneous mixture of both. After mixing, the mixtures were kept for heating at 800⁰C in a furnace for half an hour. In this way, the powders of pure material and composite of SnO₂:In₂O₃ were prepared for active sensing layer of Gas Sensors.

The paste of the material was prepared by using screen-printing technique. Butyl Carbitol Acetate were used for the screen-printing process [4-7], as a binders. The active powder and Ethyl cellulose were mixed thoroughly. During this mixing process, the Butyl Carbitol Acetate was added drop by drop to obtain the proper paste.

The glass substrate of size 7.5 x 2.5 cm² was used. The substrate is an important part of any thick-film process. For normal electronic purpose, the substrates structure should be rectangle. And before used it cleaned by using distilled water and acetone.

The screen-printing of paste of active powder mixture was done in different steps as shown in Fig. 1.1 (A to I)

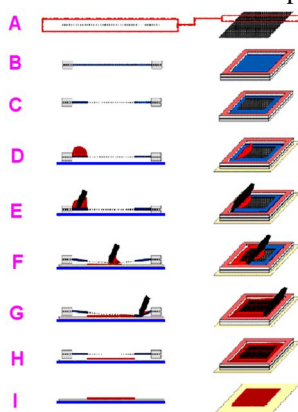


Fig. 1.1 Different steps involved in screen-printing

These samples were further heated at 150°C for 2h with a heating and cooling rate of 20°C/min to remove binder. These samples were used to analyze the gas sensing properties in air ambient and with Ammonia gas atmosphere.

B. Electrical Properties Measurement

The conductivity properties were studied between resistance and temperature by static gas characterization system shown in Fig. 1.2.

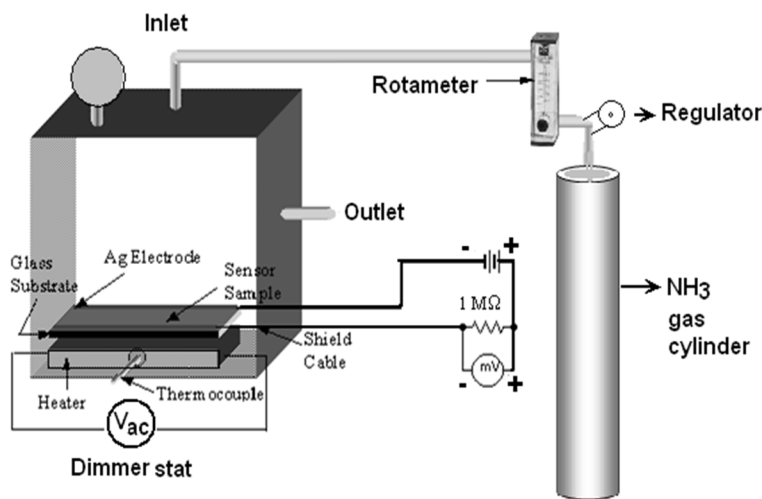


Fig. 1.2 Schematic diagram of Gas Sensing System

The sensing performance of the sample/material prepared under the optimized processing parameters were studied by using the various measurements i.e. sensitivity (S), stability, selectivity, response and recovery time of the sensor, lower detection limit (LDL), dynamic response & static response.

Resistance of the sample was measured in the air atmosphere as well as in the presence of testing gas at room temperature. In this method, resistance of $R = 1M\Omega$ was connected in series with the material and used DC supply (0-5V).(Fig 1.3)

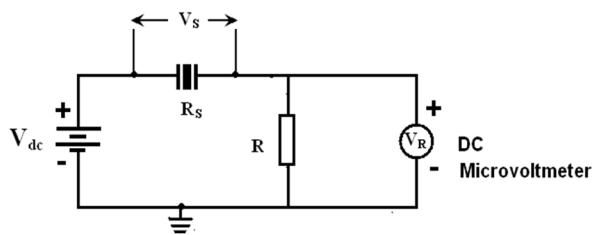


Fig. 1.3 Measurement of sample resistance

Sample resistance was calculated

$$R_s = \left(\frac{V_{dc}}{V_R} - 1 \right) R_{Eff}$$

Where, R_{Eff} is the effective resistance of parallel combination of R and internal impedance of DC microvoltmeter.

The characteristics of the device to perceive the change in the properties of the sensing material when exposed to gas is referred as sensitivity and it is generally denoted by 'S' and is expressed as

$$S = \left(\frac{R_{air} - R_{gas}}{R_{air}} \right) = \left(\frac{\Delta R}{R_{air}} \right)$$

III. RESULTS AND DISCUSSIONS

A. SEM Analysis

The surface morphology of SnO_2 , In_2O_3 , $65SnO_2:45In_2O_3$ material was studied by SEM and its picture is shown in the Fig. 1.4 to 1.6.

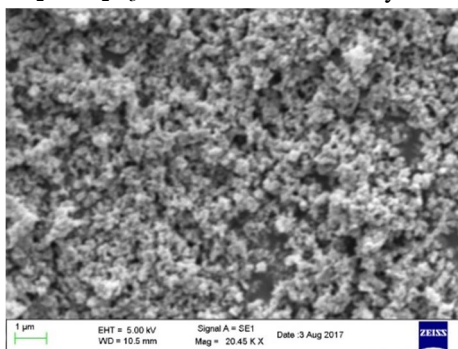


Fig.1.4 SEM picture of SnO_2

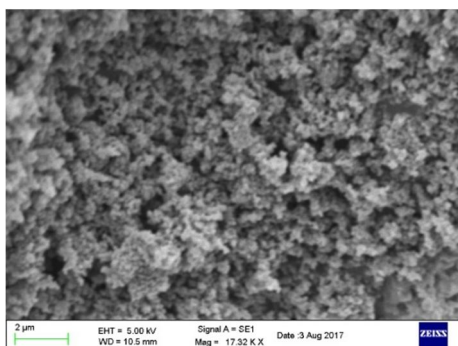


Fig.1.5 SEM picture of In_2O_3

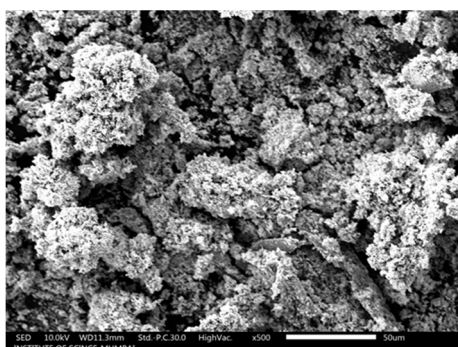


Fig.1.6 SEM picture of $65SnO_2:45 In_2O_3$

From above SEM images it is also observed that $65SnO_2:45In_2O_3$ is porous in nature. In Some section of SEM images shows some rods with fine voids over them which helps to enhance gas sensing properties.

Table 1.1 Average diameter of pore and number of pores per inch of pure samples and their compositions

Sr. No.	Pure sample and their compositions (mole %)	Average diameter of pore (nm)
1	SnO ₂	564
2	In ₂ O ₃	653
3	65SnO ₂ :45In ₂ O ₃	234

It is also found that average diameter of pore in case of these composition is small as compared to pure metal oxides (Table 1.1). This also tends to exhibit large surface area and high response of the sample.

B. EDAX Analysis

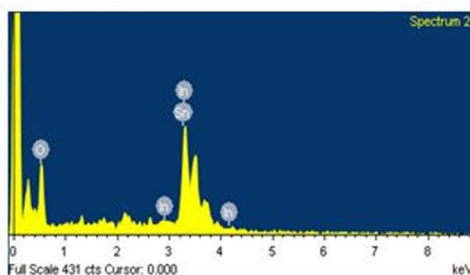


Fig. 1.7 EDAX picture of 65SnO₂:45 In₂O₃

Table 1.2 Data for EDAX

Element	Weight%	Atomic%
O K	23.98	69.72
In L	55.33	22.28
Sn L	20.69	8
Totals	100.00	

The presence of elemental composition of oxygen, Indium and tin were confirmed by the analysis through EADX spectrometers (Fig 1.7). The horizontal axis displays energy in KeV and vertical axis displays the number of X-ray counts. (Table 1.2)

C. Gas Sensing Properties

The variations of sensitivity of Pure SnO₂, Pure In₂O₃ and SnO₂: In₂O₃ compositions with concentration of ammonia gas at room temperature are shown in Fig. 1.8.

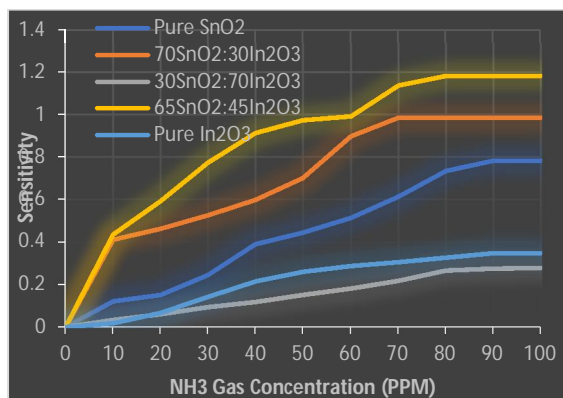


Fig. 1.8 Variation of sensitivity of SnO₂:In₂O₃ system with NH₃ gas concentration (ppm) at room temperature (303 K).

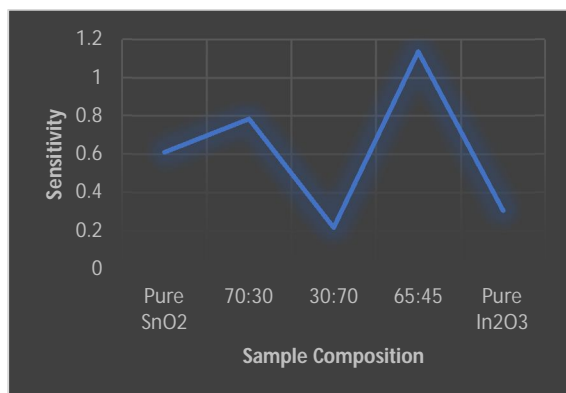


Fig. 1.9 Variation of sensitivity with SnO₂:In₂O₃ (mole %) at 70 ppm of NH₃ gas at 303 K

From Fig. 1.9, it is observed that for Pure Oxide Samples like Pure SnO₂ and Pure In₂O₃ sensitivity is less. It is observed from the curve sensitivity increases for composite samples and becomes maximum for 65SnO₂:45In₂O₃ composition. From SEM picture, it is found that porosity of 65SnO₂:45In₂O₃ composition is large as compared to other Pure SnO₂ and Pure In₂O₃, thus active surface area is more. Also the average crystallite size of 65SnO₂:45In₂O₃ composition is small and it means large active surface area. That's why sensitivity of 65SnO₂:45In₂O₃ composition is large as compared to other compositions and pure samples.

D. Static Response

Fig 1.10 Static response under static condition, it is observed that response is fast for 65SnO₂:45In₂O₃. It is also observed that recovery time for all sensors is very slow than the response time. The response and recovery time for all sensors for 70 ppm Ammonia gas concentration are calculated. Response time for optimize sensor i.e 65SnO₂:45In₂O₃ is 90 S and recovery time is 170S

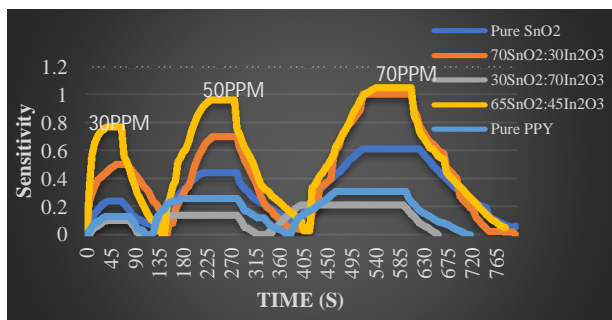


Fig.1.10 Step response of SnO₂:In₂O₃ series

E. Stability of Sensor

Sensor stability is expressed in terms of measurement of resistance with time. It is defined as the change in resistance of sensor with time [8,9].The resistance values of optimize sensors, measured with time at room temperatures it gives stable response from fig 1.11.

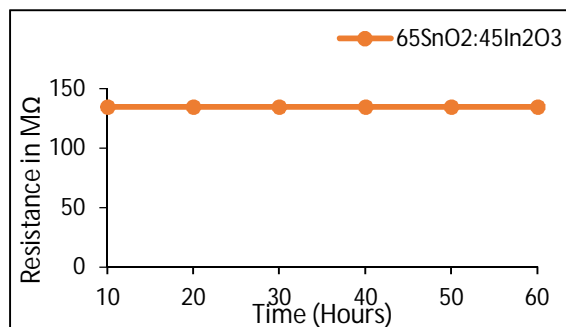


Fig. 1.11 Variation of resistance of sensors with time in air

F. Lower Detection Limit (LDL)

It is the minimum concentration of the gas that the sensor can detect. It is observed that 65SnO₂:45In₂O₃ composition sample is detected 7PPM concentration of gas.

IV. CONCLUSION

The gas-sensing properties of SnO₂:In₂O₃ Screen printing thick films towards Ammonia Gas have been investigated and compared to those of single oxide In₂O₃ and SnO₂. The pure thick film of SnO₂ and In₂O₃ sensors showed low response than the composite films to NH₃. In general, the best performances in terms of response, recovery, sensitivity and low detection limit were found in 65SnO₂:45In₂O₃ sensor. This sensor showed higher sensitivity than pure In₂O₃ and SnO₂, due a *n*-doping of Sn cations in In₂O₃ lattice, and higher defectiveness than single oxides. The NH₃-sensing of the sensors were also discussed in function of the gas/surface interaction processes and different detection mechanisms were proposed for the two oxides.

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