

Enhanced acetone vapour detection with fast response & recovery based on cobalt doped ZnO Nanostructures

¹ D.Madhesh*, ² S.P.SubinDavid, ³ S.Kalaiselvam

^{1,*} Department of Mechanical Engineering, Jeppiaar Engineering College, Chennai, India

² Department of Applied Science and Technology, Anna University, Chennai, India.

³ Department of Mechanical Engineering, Anna University, Chennai, India

*Corresponding author: E-Mail: dmadhesh@gmail.com

ABSTRACT

Cobalt doped and undoped ZnO nanostructures were synthesized using the chemical precipitation method. The prepared cobalt doped ZnO shows fast response and recovery time to acetone vapour. The electrochemical characteristics, structures and morphologies of the prepared materials are studied using X-Ray diffraction analysis (XRD) and Scanning electron microscope (SEM). The cobalt doped ZnO has porosity with high surface area which increase the sensitivity of the material in acetone vapour environment. The gas sensing properties of the prepared cobalt doped ZnO material were examined at different temperatures and different concentrations.

KEY WORDS: Acetone, ZnO, Cobalt, Gas sensor.

1. INTRODUCTION

Studies revealed that the acetone concentration in human breath is directly related to diabetes. Exhale breath consists of carbon dioxide, oxygen, water, nitrogen and volatile organic components such as acetone, methane, ethane (Phillips, 1999). Diabetes is a major cause of death in the world, more than a million life loss each year due to diabetes. The number of people suffering from diabetes is keeping on a steep rising (Wild, 2004). Diabetes can be diagnosis using a simple and cheap breath analyzer. The present breath analysis is first introduced in 1970 with a wide range of components in human breath (Pauling, 1971). These types of gas sensor are commonly used in many fields such as environmental air monitoring (Garcia Dos, 1999), alcohol detecting (Gu, 2012). This paper deals with the metal oxide gas sensors. These types of sensors use metal oxide semiconductors as the sensing materials. There are different types of metal oxide semiconductors used for the sensing materials such as Different types of metal oxides were analyzed for their capabilities in gas sensing such as SnO₂ (Wang, 2013), ZnO (Chen, 2013), NiO (Lai, 2012), WO₃ (Yang, 2014), In₂O₃ (Chen, 2013), TiO₂ (Farbod, 2014) with different morphologies like nanoflakes, nanoflowers, nanotubes, nanobelts, nanorods, nanowires were used for gas sensing materials (Shen, 2009; Grasset, 2008). The working principal of the metal oxide gas sensors are the electrical conductivity of the sensing materials changes in the reduction gas environment. These types of sensors operate under a high temperature at around 400°C. In this high temperature the sensing materials get oxidized thus the electrons get trapped and the conductivity gets decreases. The trapped electrons get released when the material get exposed in the reduction gas environment thus the conductivity increases. These sensors have three main components heater, electrode and sensing materials.

In this paper cobalt doped and undoped ZnO nanostructures synthesized using chemical precipitation method. ZnO is the commonly used material for gas sensing due to their sensitivity and stability in the reduction gas environment. Cobalt doped ZnO shows high sensing towards acetone detection. Cobalt doped shows three fold high sensing than the undoped and also cobalt doped shows fast response and recovery time than the undoped. The result shows a promising material for acetone vapour sensing

2. EXPERIMENT

All chemicals were purchased from Sigma Aldrich and used without further purification. Cobalt doped and undoped ZnO were synthesized using simple chemical precipitation method. In this method of synthesis 1.5g of Zn(NO₃)₂·6H₂O is dissolved in a 20ml of distilled water and an equal amount of ethanol and stirred for 20min in 30°C. Simultaneously 0.8g NaOH is dissolved in 20ml of distilled water, they both mixed together under continuous stirring. The prepared solution was transferred in a 150ml Teflon stain steel autoclave and maintains in an 180°C for 16h then cool down to room temperature. The prepared product was centrifuge and washed by distilled water and absolute ethanol and dried at 70°C for 10h. After that annealing process was taken place at 600°C for 4h.

Cobalt nitrate is dissolved in distilled water for a 0.1M Aqua solution. The solution is to come down to pH10 by using 0.5M NaOH. The solution stirred at 60°C for 10h. The solution was filtered, washed and calcinated at 400°C for 6h.

The morphology of the prepared materials was viewed by scanning electron microscope (SEM). The gas sensing properties of the materials in acetone vapour environment is examined using custom gas testing chamber.

3. RESULTS AND DISCUSSION

Resistance in air of the prepared Co doped and undoped ZnO materials: The fig.1 shows the resistance in air of the prepared Co doped and undoped ZnO materials. The testing undergoes at different temperatures to find out the

overall response of the materials at different temperatures. The synthesized Co doped ZnO materials resistance in air shows high response at 300°C with the response value of 1.5kΩ which is three folds higher than that of the pure ZnO. The peak response of the prepared material of pure ZnO shows at 300°C with the response value of 0.4 kΩ and it gradually decreases but the Cobalt doped ZnO shows good response between 250°C to 350°C.

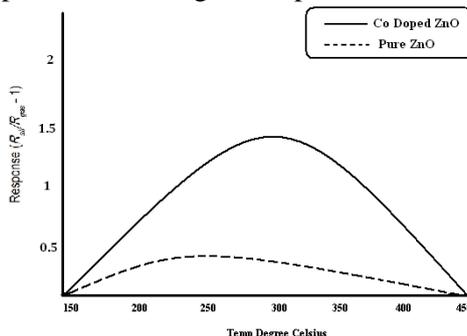


Figure.1. Resistance in air of the prepared Co doped and undoped ZnO materials

Acetone vapours in different temperature: The fig.2 shows acetone vapour concentration of 50ppm constantly. The gas testing undergoes at different temperatures to find out the optimum temperature at which the prepared material gets the peak response. The synthesized Co doped ZnO shows high response at 300°C with the response value of 2.8kΩ which is significantly higher than that of the pure ZnO which is great improvement for the acetone sensors. The peak response of the prepared material of pure ZnO for the concentration of 50ppm shows at 350°C with a response value of 1.2 kΩ and it gradually decreases but the Cobalt doped ZnO shows good response between 250°C to 400°C where the oxygen get reduced when the acetone molecules gets in contact with the Cobalt doped ZnO material.

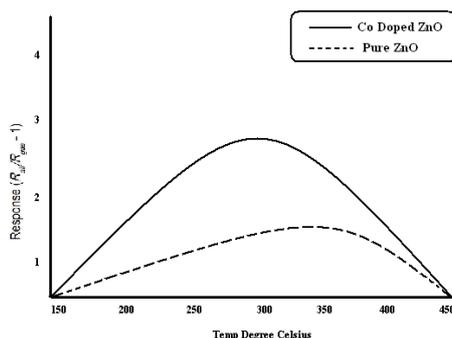


Figure.2. Acetone vapour concentrations shows the acetone vapour concentration of 50ppm environment in a closed chamber The response of 10ppm acetone vapours in different temperature ranging from 150°C to 450°C

Cobalt doped and undoped ZnO materials temperature of 300°C: The test was done to measure the response difference between the cobalt doped and undoped ZnO materials in different concentration. Fig.3 shows Cobalt doped and undoped ZnO materials with different concentration but maintained a constant temperature of 300°C. The acetone gas concentration is used from 10ppm to 100ppm and temperature is maintained constantly at 300°C. The graph reveals that the cobalt doped ZnO have the overall higher response than the pure ZnO. It also shows that the Cobalt doped ZnO have the higher response with the resistance in gas value of 3.5kΩ at 50ppm.

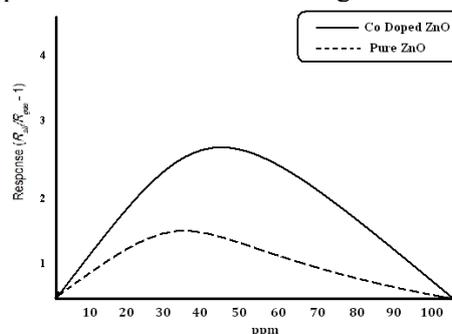


Figure.3. Cobalt doped and undoped ZnO materials temperature of 300°C

Cobalt doped ZnO material temperature of 200°C and 300°C: In order to investigate the Cobalt doped ZnO materials behavior in different acetone vapour concentration at different temperature. Fig.4 shows Cobalt doped ZnO

material with different concentration and a constant temperature of 200°C and 300°C. The testing temperature of the prepared material is taken as 200°C and 300°C because this is the optimal temperature for the materials where it shows an overall good response for the acetone vapour which was defined from the previous obtained results. From the test it once again reveals that the Cobalt doped ZnO shows higher response at 300°C in 50ppm concentration. The overall response is higher for the materials at 300°C compared to the temperature at 200°C.

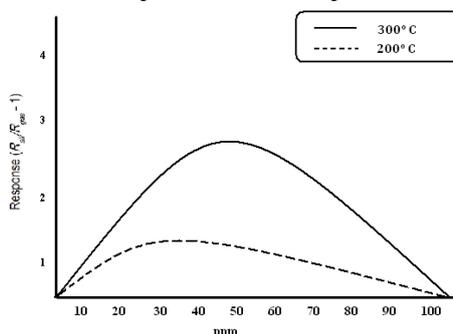


Figure.4. Cobalt doped ZnO material temperature of 200°C and 300°C

The time interval of response and recovery for the prepared pure ZnO material: The test was conducted in order to know the response and recovery time of the prepared cobalt doped and undoped ZnO materials. Fig.5 shows the time interval of response and recovery for the prepared pure ZnO material for the test the acetone concentration is maintained at 50ppm and the temperature is constantly maintained at 300°C. The time interval for the response is taken as of the materials response reaches 90% from the time acetone gas passes through the chamber. As for the recovery of the materials exposed to acetone vapour the time interval is calculated from the response drop till it reaches 10% response. The pure ZnO have a response time interval of 62s while the recovery time is 60s. The overall test shows ZnO materials have shorter time for the response and recovery for the acetone vapour sensing.

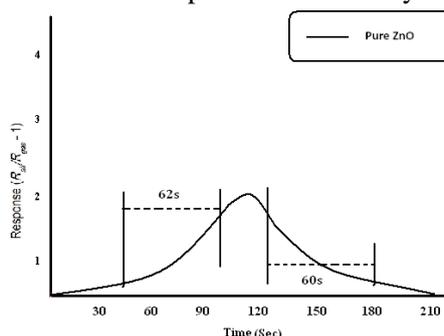


Figure.5. The time interval of response and recovery for the prepared pure ZnO material

The time interval of response and recovery for the prepared Cobalt doped ZnO material: Fig .6 shows the time interval of response and recovery for the prepared Cobalt doped ZnO material as for the test the chamber is maintained at a stable concentration of 50ppm with a constant temperature at 300°C. The test reveals that the Cobalt doped ZnO have shorter time for response and recovery which is twice faster when compare with the pure ZnO. The response time is just 36s and for recovery its 50s which is a good outcome for the acetone vapour sensors. Due to the shorter time response the prepared Cobalt doped ZnO material is capable for Diabetes detection based sensors.

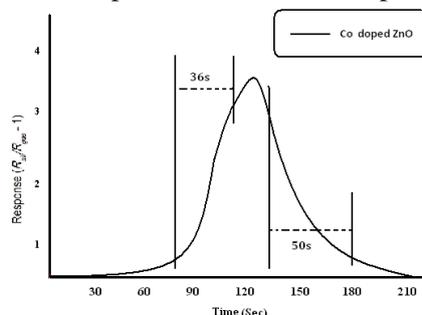


Figure.6. The time interval of response and recovery for the prepared Cobalt doped ZnO material

4. CONCLUSION

Cobalt doped and undoped ZnO was successfully prepared by the chemical precipitation method. The experiments reveals ZnO itself a superior material for acetone vapour sensing which further gives a significant improvement when doped with Cobalt. The cobalt doped ZnO have fast response and recovery and the materials

resistance remains same which proves the sensors long term stability. High response at the temperature of 300°C proves a promising material for the effective acetone vapour sensor.

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