Sensing Behavior Study of Cobalt Zinc Ferrite Nanoparticles Against Acetone in Various Temperatures

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ABSTRACT:
The Cobalt zinc ferrite nanoparticles with diameters less than 20 nm were prepared. By XRD (X-ray diffraction), Scanning Electron Microscopy (SEM) and Transmission Electron Microscopy (TEM) the morphology and the structure of this ferrite were studied. The X-ray analysis shows the formation of manganese zinc ferrite in the spinel phase. SEM photograph is shown the spherical shape of nanoparticles. And the TEM confirmed the nanoscale dimensions of the samples. The cobalt zinc ferrite nanoparticles crystallite sizes, calculated by the Debye-Scherer formula, were found near 13 nm. The sensitivity properties of this ferrite are investigated in a totally isolated plexi glass box. By injecting 1 mL of liquid and vaporizing it, we will have 200 ppm concentration of each sample in this box. Then the injected vapored sample in this box is exposed to the ferrite. After this step, the conductivity of the ferrite in a closed circuit was changed. By changing the sample type, amount of this conductivity was varied. Six gases were tested in this project: ethanol, nitrile alcohol, dimethyl formamide, carbon tetrachloride, acetonitrile, and acetone. Among these samples, the carbon tetrachloride had the best sensitivity performance. Finally, the sensor equation for carbon tetrachloride was extracted by applying different concentrations of it from 20 to 200 ppm.

KEYWORDS: Acetone Sensor, Ferrite, Gas Sensor, Cobalt Zinc Ferrite Nanoparticle, Sensitivity, X–Ray Diffraction.

1. INTRODUCTION

Metal oxide sensors on a nanoscale show sensitive and selective behavior [1-7]. Hence by applying various metal oxides we will have a wide range of materials for this purpose [8-13]. Nano-structured materials present new opportunities for enhancing the properties and performances of gas sensors because of the much higher surface materials compared to micro and macro-grained materials. Hence, to enhanced sensitivity demonstrated by the nanostructured sensors, the sensors responded more quickly for certain gas sensor applications [14- 25].

Previous reports on the sensing properties of ferrite nanoparticles have been given in various fields. Zn-Cu Ferrite and Ni-Co-Mn Ferrites present suitable response to LPG [26- 27]. Some semiconductors like, ZnO displays response to LPG, even at room temperature [28]. Zn-Mn Ferrite shows reasonable response to ethanol [29]. ZnO also has a good response to formaldehyde [30]. Finally, Mn-Ni Ferrite gives a well response to humidity [31].

Nano-sized cobalt zinc ferrites are found to exhibit interesting gas sensing properties. In these studies, the response of this ferrite for gas samples above 200 ppm

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concentration of gas was reported.

In this present paper, we report the carbon tetrachloride sensing properties of Co–Zn ferrite nanomaterials synthesized by a co-precipitation method. The materials are tested for a response towards different gases Such as ethanol, nitrile alcohol, dimethyl formamide, acetonitrile, and acetone. It is found that manganese zinc ferrite nanoparticles present the best response against carbon tetrachloride.

2. EXPERIMENTAL

2.1. $Co_{0.5}Zn_{0.5}Fe_2O_4$ Nanoparticles Synthesis

Section for the synthesis of this ferrite, the chemical reagents with high purity were prepared by Merck Company. At first zinc chloride, nickel chloride, and ferric chloride solutions, by the molar ratio of 1:1:4 were dissolved in double-distilled water. The zinc chloride and nickel chloride solutions were added drop wise to the ferric chloride solution for 10 minutes. After this time 9.0 M NaOH solution was added to this solution until the pH solution reached 12. During this time, the manganese zinc ferrite nanoparticles were precipitated from the solution. Then the final mixture was stirred for 30 min. Then the resultant mixture was filtered. And powder was washed several times with distilled water and was dried at 100ºC temperature. After this step, the sample was heated at 500ºC for 3 hours.

$$0.5CoCl_2+0.5ZnCl_2+2FeCl_3+8NaOH \rightarrow Co_{0.5}Zn_{0.5}Fe_2O_4 + 8NaCl + 4H_2O \quad (1)$$

XRD (X-Ray Diffraction, Bruker D8 ADVANCE λ=0.154nm Cu Kα radiation), SEM (scanning electron microscopy) and TEM (Transmission Electron Microscopy) were used to investigate the particles size distribution.

The structural coherence length can be calculated based on the Scherrer equation:

$$D = 0.9\,\lambda/\beta\,\cos\theta \quad (2)$$

Where, D is the crystalline size in nm, λ the Cu-Kα wavelength (0.154nm), β is the half-width of the peak in radians (instrumental line width subtracted) and is the corresponding diffraction angle.

2.2. Interface Preparation

Similar to Fig. 1, the copper wire of 0.2 mm thickness was attached to the mica surface by 1.4 cm diameter. Then 0.2 g $Co_{0.5}Zn_{0.5}Fe_2O_4$ nano powder that calcinated at 500 ºC was pressed in a cylinder of 14 mm diameter for 30 min. In Fig. 2, a schematic cross-section of the applied interface from two, right side and left side views is presented. The output copper wires were connected to a resistant circuit.

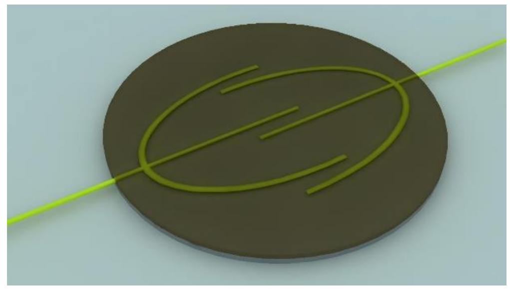


Fig. 1. Schematic figure of applied interface.

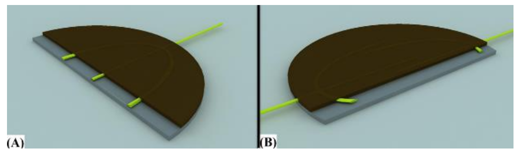


Fig. 2. Schematic cross section of applied interface from two (A), right side and (B), left side view.

3. RESULTS AND DISCUSSION

3.1. Particle Size Determination

XRD patterns of $Co_{0.5}Zn_{0.5}Fe_2O_4$ nanoparticles were shown in Fig. 3. As can be seen, all of the samples have a single phase and also have the ferrite spinel structure. The mean size of the particles was determined by the Debye-Scherer formula. It was found at 13nm.

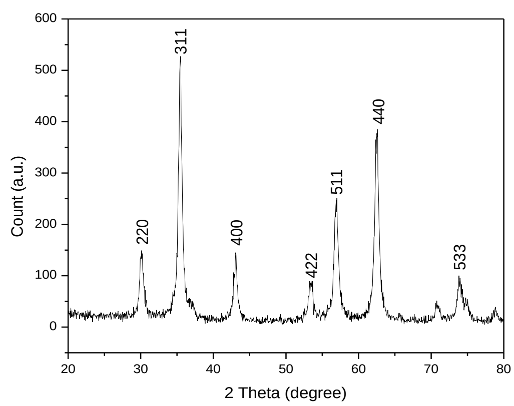


Fig. 3. XRD pattern of the $Co_{0.5}Zn_{0.5}Fe_2O_4$ nano particles.

A scanning electron microscope was employed to obtain the grain size and surface morphology of the material. SEM photograph of the $Co_{0.5}Zn_{0.5}Fe_2O_4$ nanoparticles is shown in Fig. 4. According to this image, the size of the nanoparticles is 18×19×25 mm.

From this figure, it is evident that the particles of $Co_{0.5}Zn_{0.5}Fe_2O_4$ nanoparticles are randomly oriented. However, the packed structure along with a few pores has been observed. These pores are responsible for the adsorption of the target gas. It is visible that the clustering of the particles decreases continuously, due to which the porosity increases and the grain size decreases which was confirmed by XRD analysis.

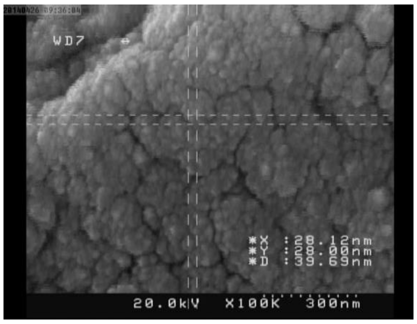


Fig. 4. SEM image of $Co_{0.5}Zn_{0.5}Fe_2O_4$ nano particles.

Fig. 5 shows the TEM photograph of the $Co_{0.5}Zn_{0.5}Fe_2O_4$ sample. It can be seen that there is a size distribution approximately in the whole of the photograph. It means that the synthesis manner has been suitable. The size of the particles was determined near 1.

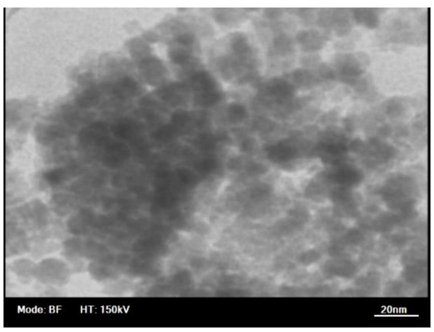
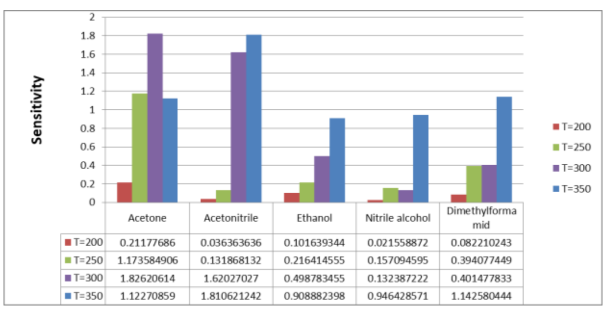


Fig. 4. TEM image of the $Co_{0.5}Zn_{0.5}Fe_2O_4$ powder after 3 hours of heating at 500ºC.

3.2. Gas Sensor Process

The resistance of this circuit was changed by various gases. With changing the concentrations of the gases, the amplitude of resistance was changed. In Fig. 5, the diagram of a variation of circuit voltage in different concentrations is displayed.



	Acetone	Acetonitrile	Ethanol	Nitrile alcohol	Dimethylformamid
T=200	0.21177686	0.036363636	0.101639344	0.021558872	0.082210243
T=250	1.173584906	0.131868132	0.216414555	0.157094595	0.394077449
T=300	1.82620614	1.62027027	0.498783455	0.132387222	0.401477833
T=350	1.12270859	1.810621242	0.908882398	0.946428571	1.142580444

Fig. 5. Diagram of sensor sensitivity in 300°C temperatures (exposed with different gases).

4. CONCLUSION

The $Co_{0.5}Zn_{0.5}Fe_2O_4$ was synthesized by simple co-precipitation method. The nanoparticle sizes were determined by a few nanometers (less than 20 nm). This size was confident by XRD and TEM studies. In the XRD pattern according to Debye-Scherrer's equation, the mean particle size is 13 nm. The TEM image confirms the cobalt ferrite nanoscale formation on the glass surface.

For sensitivity investigations, a sensor interface was prepared. This interface was exposed to six: ethanol, nitrile alcohol, dimethyl formamide, carbon tetrachloride, acetonitrile, and acetone gases. The best response was achieved for carbon tetrachloride. Finally, the sensor equation was extracted for acetone in the concentration region, between 20-200 ppm.

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