World Academy of Science, Engineering and Technology
International Journal of Materials and Metallurgical Engineering
Vol:17, No:12, 2023

Control of Building Ventilation with CO_2 Gas Sensors Based on Doped Magnesium Ferrite Nanoparticles for the Development of Construction and Infrastructure Industry

Maryam Kiani, Abdul Basit Kiani

Open Science Index, Materials and Metallurgical Engineering Vol:17, No:12, 2023 publications.waset.org/10013407.pdf

Abstract**—**To develop construction and infrastructure industry, sensors are highly desired to control building ventilation. Zinc doped magnesium ferrite nanoparticles (Z@MFO) (Zn = 0.0, 0.2, 0.3, 0.4) were prepared in this paper. Structural analyses confirmed the formation of spinel cubic nanostructures. X-Ray diffraction (XRD) data represent high reactive surface area due to small average particle size about 15 nm, which efficiently influences the gas sensing mechanism. The gas sensing property of Z@MFO for several gases was obtained by measuring the resistance as a function of different factors, such as composition and response time in air and in presence of gas. The sensitivity of spinel ferrite to CO_2 at room temperature has been compared. The Z@MFO nano-structure exhibited high sensitivity represented good response time of (~1 min) to CO_2, demonstrated that the material can be used in the field of gas sensors with high sensitivity and good selectivity at room temperature to control building ventilation. CO_2 gas sensors play a vital role in ensuring the safety, comfort, and sustainability of modern building environments.

Keywords**—**$MgFe_2O_4$ nanoparticles, synthesis, gas sensing properties, X ray differentiation.

I. INTRODUCTION

IN today's world, ensuring the safety and well-being of occupants in buildings is of paramount importance. Carbon dioxide and carbon mono-oxide gases can pose significant risks if not detected and controlled promptly. This is where CO_2 gas sensors play a crucial role in maintaining optimal indoor air quality by controlling building ventilation systems. Gas sensors are vital components in building management systems, enabling the implementation of proactive ventilation control strategies. By constantly monitoring CO_2 gas levels, these sensors ensure that the ventilation system responds promptly in high-risk situations, such as malfunctioning fuel-burning appliances or increased occupant density. This responsive control helps prevent the buildup of CO gas to dangerous levels, mitigating the risk of carbon monoxide poisoning. Efficient ventilation control based on gas sensor data ensures improved indoor air quality. By providing real-time feedback on gas concentrations, the sensors enable ventilation systems to adjust airflow rates and meet the required ventilation standards. This not only removes harmful pollutants but also replenishes fresh air, thus creating a healthier and more comfortable environment for building occupants. Fig. 1 represents the schematics of smart building gas sensors to control air pollution and building ventilation.

In the current era, spinal ferrite nanoparticles have great importance due to their remarkable properties for several research fields and tecnology such as energy applications, catalysis, water purification, mineral separation, drug delivery system, cancer treatment, and development of gas sensing technology to avoid gas pollutants from environment, automobile drain and biological exposures [1], [2]. Gas sensing nanomaterials are an exciting and innovative area of scientific research that has the potential to revolutionize various industries, from environmental monitoring to medical diagnostics. These nanomaterials possess unique properties that make them highly sensitive to different types of gases, allowing for the detection and analysis of their presence in a wide range of applications. At the heart of gas sensing nanomaterials are tiny particles or structures that have dimensions at the nanoscale, typically ranging from 1 to 100 nanometers. These materials can be tailored to have specific properties, such as high surface area, enhanced conductivity, or selective reactivity with certain gas molecules [3]-[7]. This customization enables them to effectively interact with different gases and provide reliable measurements. One of the most widely explored types of gas sensing nanomaterials is metal oxides, such as tin oxide (SnO_2), zinc oxide (ZnO), and titanium dioxide (TiO_2) [7]-[15]. These metal oxides exhibit excellent gas sensing capabilities due to their unique electronic and surface properties.

II. PROCEDURE FOR PREPARATION OF GAS SENSOR NANOMATERIALS

A. Synthesis

Z@MFO nanoparticles were prepared by co-precipitation method. This process is a convenient, environment friendly, inexpensive, high-yielding, low cost and facile synthesis technique for the preparation of spinel ferrite nanomaterials, which included the following procedure: A.R. grade Fe $(NO_3)_3{\cdot}9H_2O$, Mg $(NO_3)_2{\cdot}6H_2O$ and Zn $(NO_3)_2.6H_2O$ were dissolved in an appropriate proportion in deionized water to

Maryam Kiani is with the College of Civil and Transportation Engineering, Shenzhen University, Shenzhen 518060 P.R. China and Prime Express Global LLC, Florida USA (e-mail: kayani.m1@hotmail.com)

Abdul Basit Kiani works with PEG LLC Florida USA.

guarantee the eradication of impurities and stirred for 30 mins at room temperature then heated at 90 °C with continuous stirring. Sample is transferred into hydrothermal autoclave for 12 h at 12 ºC. After that, sample is filter out and washed with demonized water and ethanol solution and then is dried in vacuum oven over the night at 80 ºC. The sample is then allowed to cool at room temperature. The dried material under investigation is finely ground into fine powder by mortar and pastel. Sample is calcined at 400 °C for 2 h and allowed to cool at room temperature. The whole procedure was repeated for different concentration of Zn in Z@MFO samples.

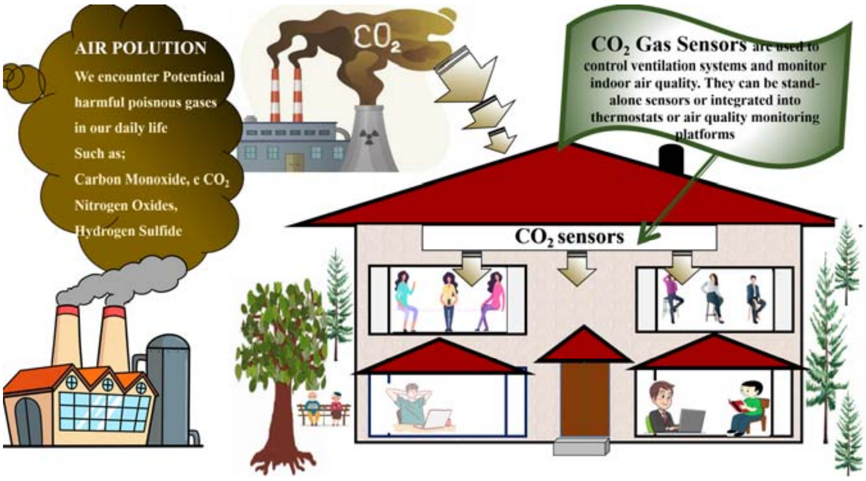

Fig. 1 Schematics of smart building gas sensors to control air pollution and building ventilation

B. Gas Sensing Measurement

A specially designed gas sensing system was used for sensing of various gases. The sensing setup is consisted of a vessel with two input and output valves. The pallet sensor was placed into the measuring chamber and outputs were connected to a Keithley Multimeter. The detail of gas sensing set-up well as measurement protocol has been demonstrated elsewhere [32]-[35]. The pallet sensor was submitted to a heat treatment for 10 minutes at 100 °C to achieve its thermodynamic stabilization. For improved and reproducible sensitivity, heat cleaning of the samples was found to be essential [36]. The sensitivity is calculated by using following relation:

$$S = \frac{\Delta R}{Ra} = \frac{|Ra-Rg|}{Ra} \tag{1}$$

where Ra is the sensor resistance in the air and Rg is the sensor resistance in the presence of test gas.

III. RESULTS AND DISCUSSION

A. Structural Properties

The structural properties of the ferrite are sensitive to the particulars of the fabrication methods. Structural properties of prepared samples were obtained by using XRD technique with generator voltage of 40 KV, current 40 mA and Cu Kα radiation (λ = 1.5406 Å). The XRD pattern of investigated samples is shown in Fig. 2. The patterns show the existence of single phase face centered cubic (FCC) structure spinel ferrite. The peaks were well defined and indexed to (220), (311), (400), (422), (511), (440), (533) and (622) diffraction planes. The peak intensity (311) was relatively higher than others. The higher intensity can be attributed to an annealing effect that boosts the crystallinity and specific orientation of the crystallites. The lattice constants for all compositions were found to be increased from 8.09 Å to 8.5 Å and average crystallite size using Scherer's equation found to be 15 ± 2 nm and it is clear from the XRD plots that the peaks shift towards lower 2θ with increasing of Zn^{2+} hence validating the increasing trends. The increase in lattice parameter with Zn contents could be explained on the basis of the ionic radii where the radius of Mg is smaller than that of the Zn ion. The mass (ρ_m) and x-ray densities (ρ_{xrd}) were calculated in accordance with formula in (1) and achieved the decreasing trends. This can be owed to doping effect, in this respect Zn^{2+} ions partially replace some of the host ions leading to the formation of neighboring oppositely charged vacancies that result in electric dipoles. The created cation vacancies may accelerate cation inter diffusion in the solution. This agrees with the lattice diffusion mechanism. Therefore, the general decrease in porosity [37] is predictable.

B. Gas Sensing Properties

The value of sensitivity for the Z@MFO sensor is relatively higher because of achieving smaller crystalline size, which gives a larger surface area for the test gas to be exposed. Further enhanced area increases the probability of gas–solid interaction, and results in the increase of sensitivity of the material. Hence, we have adopted the co-precipitation method in all our further experimentation. The detection mechanism of these ferrite materials is based on the property of changing the resistance of sensing material in the presence of a determinate gas. A porous structure favors the gas molecules to enter easier into the material as it is known that the pores may offer tunnels to transit the gas into the ferrite samples and could lift the adsorption of tested gas. Firstly, the atmospheric oxygen adsorbs on the surface of sensing material by extracting electrons from the conduction band to form super oxides or peroxides. This would result the oxygen deficiency in the bulk of the material preferably at the surface. Fig. 3 revealed that the resistance of prepared sensors increased at lower concentration of Zn and then decreased with the increasing Zn concentration. This phenomenon can be elaborated by the adsorption of gas molecules and then desorption. The sensitivities of the four ferrite-based gas sensors (Z@MFO) (Zn = 0.0, 0.2, 0.3, 0.4) towards the gases, CO_2, decrease due to decrease in number of pores with increasing doping content of Zn. The nano structured samples showed exclusive sensitivity (see (1)) to CO_2 gas at room temperature, whereas sensitivity to other gases was comparatively low. The sensing characteristics gives an idea of the response time and defined as the time taken by the sensor to reach 50% of the final response. It is found that as prepared nanocomposite shows a rise time (response time) of ~ 1 min for CO_2.

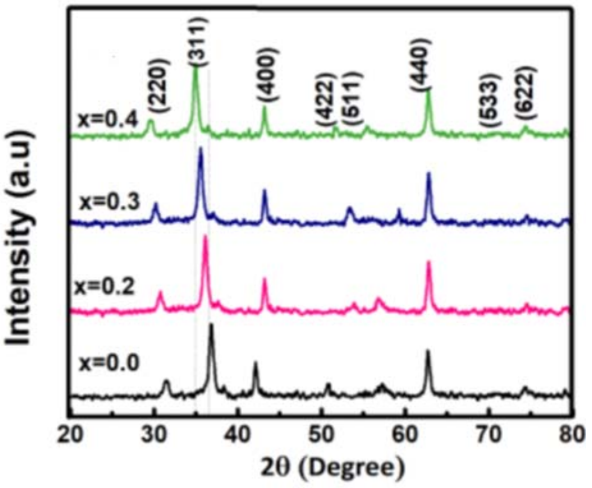

Fig. 2 XRD pattern corresponds to all diffraction planes with most intense peak (311) of (Zn = 0.0, x = 0.2, x = 0.3 and x = 0.4)

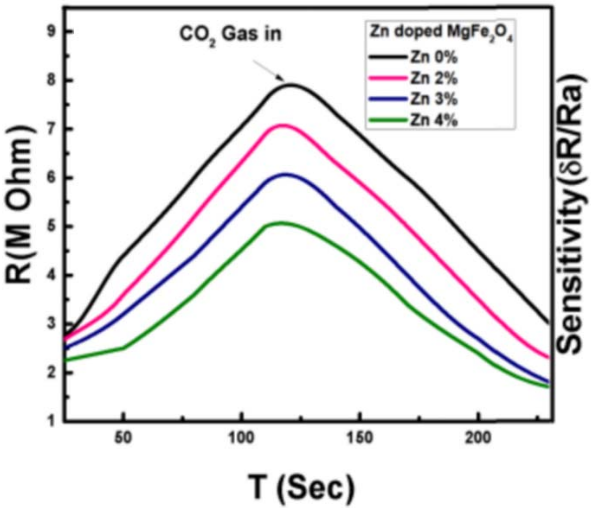

Fig. 3 CO_2 Gas sensitivity a function of Zn concentration in zinc doped magnesium ferrite-based sensor

IV. CONCLUSION

Zinc doped magnesium ferrite nanoparticles were synthesized in wet chemical lab successfully and well characterized by XRD. The samples were found to be FCC spinel nanostructures, and crystalline size in the range of 15 nm. Variation in crystallinity, surface area, particle size and sensing properties of the ferrite NPs with different concentration of Zn doping were observed. The results show the effects of Zn ions in Mg ferrite on gas sensitivity. The sensor showed good response of ~ 1 min to CO_2 gas at initial content of Zn, and sensitivity was decreased with further increase in Zn concentration. It was observed that the gas sensitivity depends on types of semiconducting material, concentration of Zn dopants in magnesium ferrite nanomaterials have useful properties and applications in the sensors technology to control building ventilation for the development of buildings safety, sustainability and infrastructure industry.

ACKNOWLEDGMENT

This work is supported by National Science Foundation China. NSFC Grant number 52350410454 and 12175150.

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