

# The Synthesis and Characterization of Zinc Oxide Nanorods and Nanoflower for Ethanol Gas Sensing Applications

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## Abstract

Zinc oxide (ZnO) nanostructures, including nanorods and nanoflowers, were successfully synthesized using the hydrothermal method and subsequently coated onto substrates via spin coating. The morphological characteristics of the ZnO nanostructures were analysed using field emission scanning electron microscopy (FESEM), revealing well-defined nanorod and nanoflower morphologies. Optical properties were evaluated using UV-visible spectroscopy, confirming the material's high optical transparency and characteristic bandgap. The gas sensing performance of the ZnO nanostructures was tested in a custom-built setup under two temperature conditions: room temperature and 150°C. The nanoflower demonstrated a better sensitivity compared to the nanorod in both conditions. These findings provide valuable insights into the development of efficient and temperature-responsive gas sensors.

## 1. Introduction

Growing technology and modern invention may ease the everyday life of humans. However, it always creates an irrevocable drawback for the environment and the planet we are living in. According to the World Health Organization (WHO), in 2019, 99% of the world's population lived in areas that did not meet the WHO air quality guidelines. It also states that just by reducing air pollution levels, the world can reduce many obstacles air pollution faces, like health issues. WHO states that 6.7 million early mortality occurs yearly due to the combined effects of ambient and household air pollution.

Gases like carbon monoxide (CO), nitrogen oxides (NO<sub>x</sub>), ozone and sulphur dioxide (SO<sub>2</sub>) are a few of the pollutants that cause air pollution [1]. Carbon monoxide is an odourless and colourless gas which contributes to air pollution and upon inhalation by living beings it can be fatal [1]. Nitrogen oxides cause health issues like asthma and environmental issues like acid rain [1]. Therefore, to detect and monitor these types of poisonous gas development of gas sensors is essential.

A gas sensor is considered a semiconductor gas sensor when it utilizes semiconductor material in its receptor and/or transducer [2]. Semiconductors can be categorized into 2; oxides and non-oxides [2]. Oxide semiconductors can be used as receptors and/or transducers [2]. However, due to the insulating layer present in the non-oxide semiconductors, they cannot be used as receptors [2]. This layer acts as a barrier to the effective interaction between the semiconductor's active sites and the target gas molecules.

The essential qualities required for a sensor include its capacity for diverse measurements, high sensitivity, the precision of data extracted, selectivity in targeting specific substances, and long-term stability [3]. Nano-scaled sensors have progressed rapidly over the decade due to their excellent properties in sensing. No fewer than one

of nanosensor dimensions is up to 100nm [4]. Nanostructured materials, such as nanowires (which offer high detection sensitivity), carbon nanotubes (known for their extremely high surface area), thin films, nanoparticles and polymer nanomaterials are used in manufacturing nanosensors[5].

Gas sensors are one of ZnO nanoparticles' most indispensable uses[6]. ZnO's crystalline nature enables it to form various nanostructures, including nanoparticles, one-dimensional (1D), two-dimensional (2D), and three-dimensional (3D) structures[7]. Material morphology significantly affects gas sensing performance. ZnO was chosen from other oxide semiconductors ( $\text{TiO}_2$ ,  $\text{SnO}_2$ ) due to its high sensitivity and low operating temperature. There are several synthesis methods for ZnO nanostructure namely: the sol-gel, precipitation, and chemical vapour deposition. The hydrothermal method was chosen due to its straightforward and operation at relatively low temperatures for calcination compared to other methods, making it more energy-efficient and easier to implement. Sonalika Agarwal et al. used a hydrothermal method to yield two ZnO nanostructures: flower-like ZnO nanostructures and floral assembly of ZnO nanorods. They studied the gas-sensing properties of these structures. They discovered that nanoflowers have more surface area and surface defects than nanorods. These variations allow flower-like ZnO to adsorb more target gas molecules, boosting responsiveness[8]. Their possible uses include electrochemical, electrical, optical, and magnetic devices. The nanostructures' low density, broad active surface area, and surface permeability make them suitable for various applications[9].

Given ZnO nanostructures' superior electron transfer rate, biomolecules can be made to reveal their latent electrochemical potential and have easier access to direct electrochemistry[10]. ZnO nanostructures offer several advantages over bulk materials, including high surface-to-volume ratio, non-toxicity, economical, chemical stability, eco-friendliness, and enhanced electron communication[11]. ZnO is ideally suited for gas sensing applications due to its thermal/chemical stability, oxidation resistance, biocompatibility, and high conductivity.

## 2. Research Method

### 2.1 Materials

All chemicals were purchased from Sigma Aldrich. Zinc nitrate hexahydrate ( $\text{Zn}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$ ), hexamethylenetetramine (HMTA), sodium hydroxide (NaOH) pellets, Polyvinylpyrrolidone (PVP), Zinc acetate dihydrate ( $\text{Zn}(\text{CH}_3\text{COO})_2 \cdot 2\text{H}_2\text{O}$ ), citric acid monohydrate ( $\text{C}_6\text{H}_8\text{O}_7 \cdot \text{H}_2\text{O}$ ). The chemical used for gas sensor testing was ethanol to produce ethanol vapor.

### 2.2 Synthesis of ZnO Nanoflower

The synthesis begins with dissolving 67 ml of deionized water, 13 ml ethanol, 0.35 g of zinc acetate dihydrate ( $\text{Zn}(\text{CH}_3\text{COO})_2 \cdot 2\text{H}_2\text{O}$ ) and 0.24 g of citric acid monohydrate ( $\text{C}_6\text{H}_8\text{O}_7 \cdot \text{H}_2\text{O}$ ) while vigorously stirring. Then 10M of NaOH solution is added till pH 13 is achieved. The homogeneous solution is then transferred into a Teflon-lined autoclave. The autoclave is placed in the oven for 17 hours at 150°C. After cooling down the white powder is washed with ethanol and deionized water multiple times. Then it is dried for 12 hours at 80°C.

### 2.3 Synthesis of ZnO Nanorod

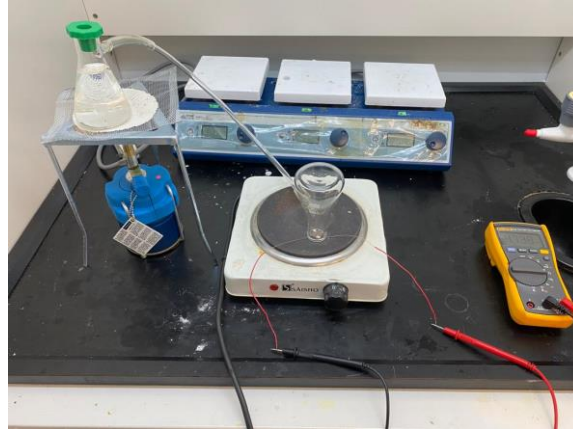
ZnO nanorods are also synthesized by hydrothermal method. The precursor solution is prepared separately. 0.1 M zinc nitrate hexahydrate and 0.1M HMTA were made for 30 minutes by stirring constantly. 40 ml of water is used to make PVP (50mg) surfactant solution. Then, it was added to the salt solution and stirred continuously for 15 minutes. The HMTA solution is mixed with the solution mixed previously dropwise for about 1 hour at room temperature. As the solution turns cloudy, it is transferred into a Teflon-lined autoclave and placed in an oven for 16 hours at 100°C. The precipitation obtained is later washed with ethanol and deionized water before drying in the oven at 60°C for 6 hours.

### 2.4 Spin Coating the FTO substrate with ZnO nanostructures

A paste was made by adding ethanol, Triton X-50 and polyvinyl alcohol along with the ZnO nanostructure. All the mentioned chemicals were added and placed on a magnetic stirrer for 30 minutes. The FTO glass was chosen due to its excellent electrical conductivity, high optical transparency, and thermal and chemical stability making it ideal for applications requiring transparent and conductive substrates. The FTO substrate was cut into 1.5cm x 1.5cm and cleaned in an ultrasonic cleaner for 10 minutes with acetone and distilled water followed by vacuum drying. The substrate was mounted on the stage of the spin coater and a few drops of the paste were placed on the FTO substrate. As the spin coater spun the excess paste was eliminated and a uniform layer of coating was achieved.

## 2.5 Characterization

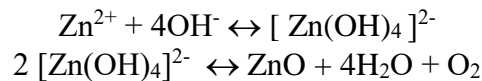
The surface morphology of the ZnO nanostructures was done by field emission scanning electron microscope (FESEM) FEI VERSA 3D Dual Beam and the optical properties were studied by UV-Vis Spectrometer HITACHI U-3900H. Field Emission Scanning Electron Microscopy (FESEM) was conducted at an accelerating voltage of 10 kV and 5kV with a magnification of 10,000x and 50,000x respectively. A homemade gas sensor setup was made to test the gas sensors' effectiveness utilizing a multimeter. The maximum temperature was set at 150°C and the minimum was at room temperature.



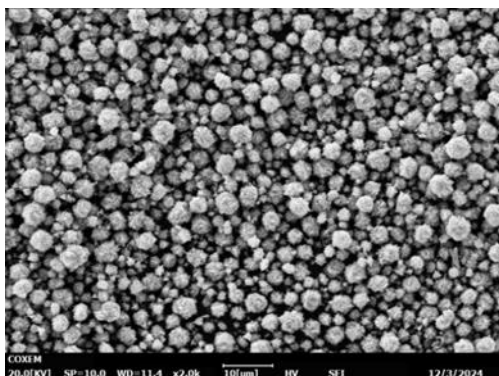
**Fig. 1** Shows the homemade set-up of the gas sensor testing chamber

## 3. Results and Discussion

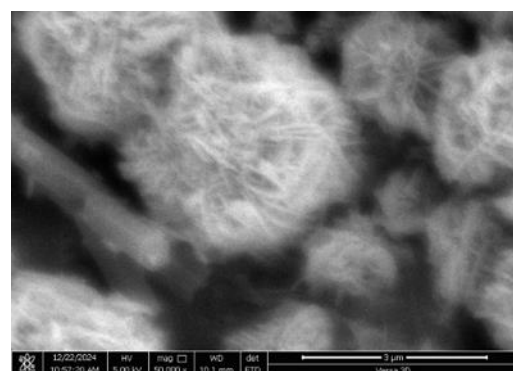
FESEM is used to characterize the surface morphology of the ZnO nanostructures as shown in Figure 1. Figure 1(a and b) shows flower-like ZnO nanostructure measured at 2 – 3 μm in size, the petals measured ranging from 500 to 700nm. The abundant amount of petals and pores in the flower-like structure of this nanoflower boosts electron transmission. The chemical equation of the hydrothermal process is as follows:



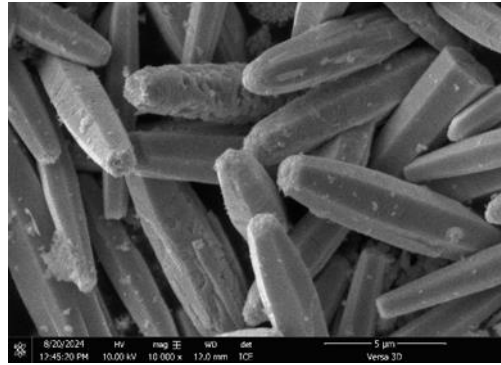
The nucleation process is the first to occur following the crystal growth. The modest nucleation pace and the rapid crystal growth are owing to the elevated pH rates. Under the regulation of experimental parameters including the precursors, the temperature and the timespan of stirring, the reaction span in the autoclave and the heating temperature it is possible to grow a perfect flower-like nanostructure. It is also possible to build a precisely detailed nanorod as depicted in Figure 1c. The ZnO nanorods illustrate a uniform distribution of diameter and length. According to the FESEM image in figure 1c, the nanorod is measured at 800 to 900nm in length. The diameter averages at 200 to 300nm. The fluctuations of the length and the diameter could have been caused by the reaction kinetics and the growth environment inside the autoclave[13].



(a)



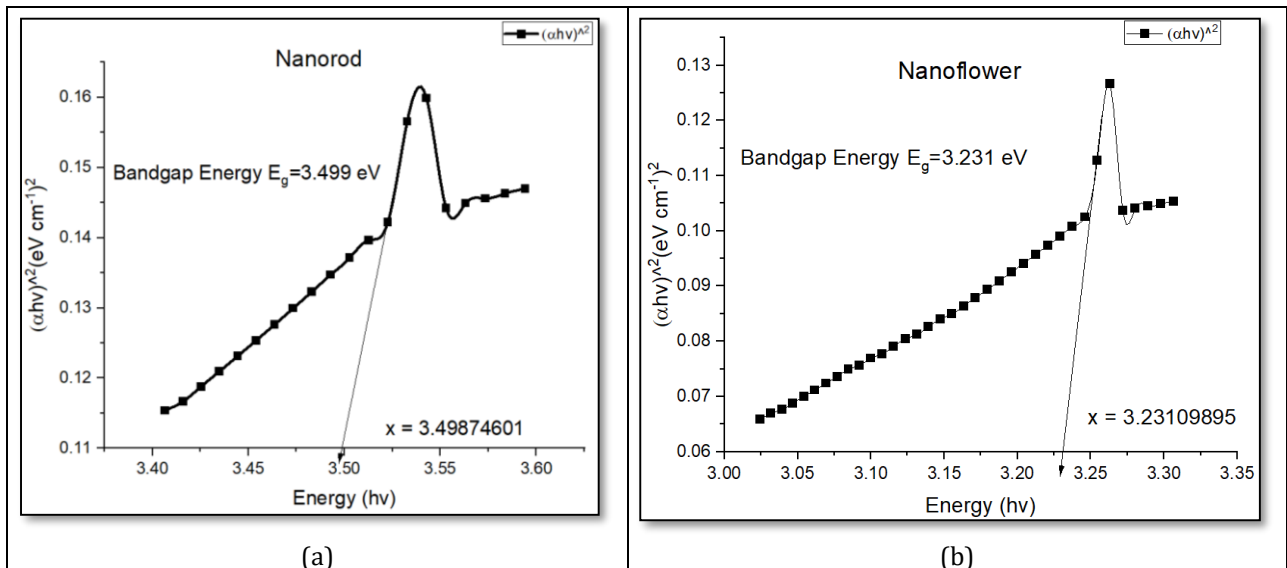
(b)



(c)

**Fig. 2** ZnO nanoflower (a) The accelerating voltage of 20kV and magnification of 2,000x (b) The accelerating voltage of 5kV and the magnification of 50,000x, ZnO nanorod (c) The accelerating voltage of 10kV and the magnification of 10,000x

The UV-visible spectroscope was utilised to study the optical properties of the synthesized ZnO nanostructures. The prime absorption altitude at ambient temperature for ZnO nanorod was 350nm. The ZnO nanoflower showed an altitude of 380nm. The band gap energy of ZnO nanostructures is determined by extrapolating the linear segment of the graph plotted between absorbance and the wavelength in the nanometer. The bandgap energy of nanorod is 3.499eV whereas the nanoflower has a bandgap energy of 3.231eV.



**Fig. 3** Shows the graph of extrapolation for the bandgap energy, (a) ZnO nanorod (b) ZnO nanoflower

The ZnO nanostructures were tested for their gas-sensing ability by employing at room temperature and 150°C. The nanostructures were tested with ethanol vapour. Figure 3 (a and b) shows the gas sensor's results when heated up to 150°C. The nanoflower shows the highest responsiveness towards the ethanol vapour compared to the nanorod. The highest drop in resistance was shown by nanoflower which is 3.5 Ω whereas the nanorod is only 2.0 Ω. The nanoflower's resistance dropped from 18.0 Ω to 14.5 Ω when it was exposed to the ethanol vapour. The nanorod, on the other hand, dropped from 16.4 Ω to 14.4 Ω. The nanoflower took approximately 40s to drop to its lowest resistance whereas the nanorod took 60s to drop to its lowest resistance.

The gas sensors tested at room temperature showed a poor response. The nanoflower's resistance dropped from 18.0 Ω to 15.7 Ω which is a 2.3 Ω difference. The nanorod had the smallest drop from 16.7Ω to 15.1Ω which is a 1.6 Ω difference. The nanoflower showed better responsiveness than nanorods even at room temperature. This is due to the distinct morphologies of the nanostructures. Nanoflower has more surface flaws and area compared to nanorod which aids in the sensitivity of the gas sensor.

The recovery rate for the nanoflower was quite rapid compared to the nanorod. In the 40s the nanoflower recovered to half of its initial baseline while the nanorod barely reached a quarter of its baseline.

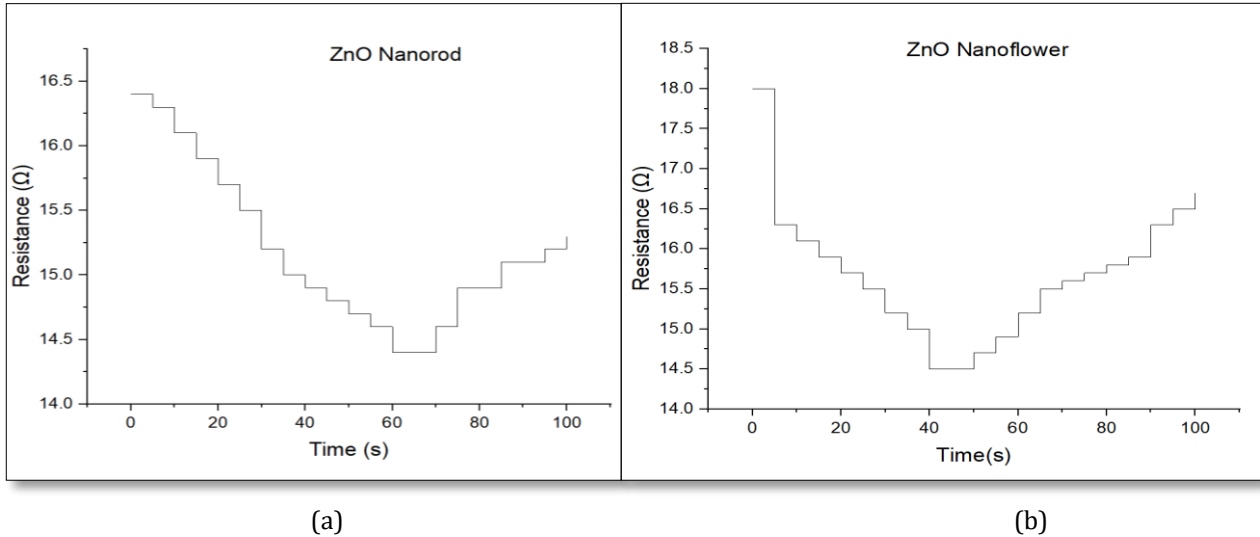


Fig. 4 Shows the graph of resistance at 150°C (a) nanorod, (b) nanoflower

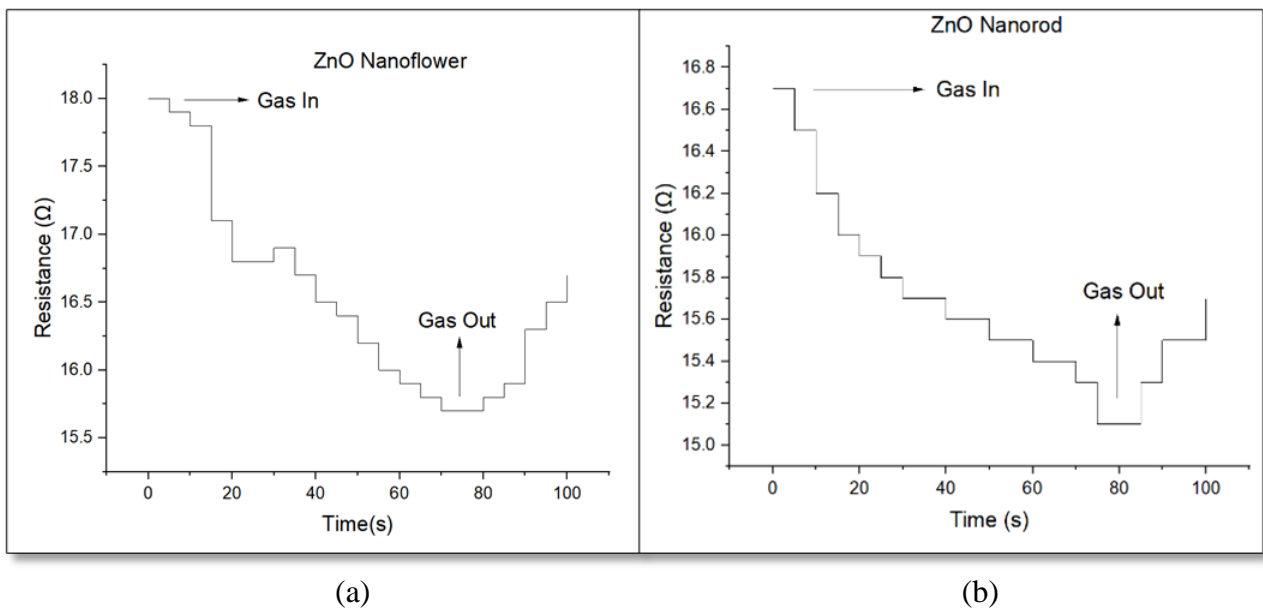


Fig. 5 Shows the graph of resistance at room temperature (a) nanoflower, (b) nanorod

#### 4. Conclusion

This extensive research used hydrothermal methodology to synthesize two different zinc oxide (ZnO) nanostructures, namely ZnO nanorods and ZnO nanoflowers. The fundamental target of this research is to examine the morphology-dependent effectiveness of these ZnO nanostructures as gas sensors for ethanol vapor. The results have outlined the bright possibilities of hydrothermally processed ZnO nanostructures for gas sensors. The FESEM analysis confirmed the distinct geometries of the synthesized nanostructures, with nanoflowers displaying a highly porous, flower-like architecture, and nanorods exhibiting a uniform, columnar structure. The gas-sensing performance of these two sensors was manually evaluated, and the ZnO nanoflower-based sensor demonstrated superior results compared to the nanorod-based sensor in terms of sensitivity, response-recovery time, and selectivity. At a temperature of 150°C, the ZnO nanoflower sensor exhibited a resistance difference of 3.5  $\Omega$ , whereas the ZnO nanorod sensor showed a smaller difference in resistance of 2.0  $\Omega$ . Similarly, at room temperature, the nanoflower sensor achieved a difference in resistance of 2.3  $\Omega$ , compared to 1.6  $\Omega$  for the nanorod sensor. The enhanced performance of the nanoflower sensor can be attributed to its unique morphology, which provides a larger surface area, increased porosity, and more active sites for gas adsorption and reaction. These features facilitated stronger and more efficient interaction with the target gas molecules, resulting in improved sensor response. In contrast, the relatively lower performance of the nanorod sensor highlights the importance of nanostructure design in tailoring material properties for specific applications. Overall, this research

highlights the potential of ZnO nanoflowers as a highly effective material for gas sensor development, particularly for applications requiring high sensitivity and fast response times.

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## Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of the paper.

## Author Contribution

The authors confirm contribution to the paper as follows: **study conception and design:** Kavita Anbalagan; **data collection:** Kavita Anbalagan; **analysis and interpretation of results:** Kavita Anbalagan, Amira Saryati Ameruddin; **draft manuscript preparation:** Kavita Anbalagan, Amira Saryati Ameruddin. All authors reviewed the results and approved the final version of the manuscript.

## References

- [1] M. V. Nikolic, V. Milovanovic, Z. Z. Vasiljevic, and Z. Stamenkovic, "Semiconductor gas sensors: Materials, technology, design, and application," Nov. 02, 2020, *MDPI AG*. doi: 10.3390/s20226694.
- [2] M. Dadkhah and J. M. Tulliani, "Nanostructured Metal Oxide Semiconductors towards Greenhouse Gas Detection," Feb. 01, 2022, *MDPI*. doi: 10.3390/chemosensors10020057.
- [3] A. J. Saleh Ahammad, J. J. Lee, and M. A. Rahman, "Electrochemical sensors based on carbon nanotubes," 2009. doi: 10.3390/s90402289.
- [4] R. Abdel-Karim, Y. Reda, and A. Abdel-Fattah, "Review—Nanostructured Materials-Based Nanosensors," *J Electrochem Soc*, vol. 167, no. 3, 2020, doi: 10.1149/1945-7111/ab67aa.
- [5] Q. Hu, E. K. Wujcik, A. Kelarakis, J. Cyriac, and X. Gong, "Carbon-Based Nanomaterials as Novel Nanosensors," 2017. doi: 10.1155/2017/3643517.
- [6] Y. Chen *et al.*, "Highly sensitive and selective acetone gas sensors based on modified ZnO nanomaterials," *Mater Sci Semicond Process*, vol. 148, 2022, doi: 10.1016/j.mssp.2022.106807.
- [7] B. Zhang *et al.*, "Sensitive H<sub>2</sub>S gas sensors employing colloidal zinc oxide quantum dots," *Sens Actuators B Chem*, vol. 249, pp. 558–563, 2017, doi: 10.1016/j.snb.2017.03.098.
- [8] S. Agarwal *et al.*, "Gas sensing properties of ZnO nanostructures (flowers/rods) synthesized by hydrothermal method," *Sens Actuators B Chem*, vol. 292, pp. 24–31, Aug. 2019, doi: 10.1016/j.snb.2019.04.083.
- [9] Y. Zhang *et al.*, "A ppb-Level Formaldehyde Gas Sensor Based on Rose-Like Nickel Oxide Nanoparticles Prepared Using Electrodeposition Process," *Nano*, vol. 11, no. 1, 2016, doi: 10.1142/S1793292016500090.
- [10] R. Yakimova, L. Selegard, V. Khranovskyy, R. Pearce, A. L. Spetz, and K. Uvdal, "ZnO materials and surface tailoring for biosensing," *Frontiers in Bioscience - Elite*, vol. 4 E, no. 1, 2012, doi: 10.2741/e374.
- [11] M. L. M. Napi, S. M. Sultan, R. Ismail, K. W. How, and M. K. Ahmad, "Electrochemical-based biosensors on different zinc oxide nanostructures: A review," 2019. doi: 10.3390/ma12182985.
- [12] Vijayakumar, B. W. Shivaraj, C. Manjunatha, B. Abhishek, G. Nagaraju, and P. K. Panda, "Hydrothermal synthesis of ZnO nanotubes for CO gas sensing," *Sensors International*, vol. 1, Jan. 2020, doi: 10.1016/j.sintl.2020.100018.
- [13] J. Manickavasagar and A. S. Ameruddin, "ENHANCED KNOWLEDGE IN SCIENCES AND TECHNOLOGY The Synthesis of Zinc Oxide Nanostructures as an effective photoanode for the applications of Dye Sensitized Solar Cells: ZnO Nanoflower, ZnO Nanorod, ZnO Nanoball," vol. 0, no. 0, pp. 1–6, 2024, doi: 10.30880/ekst.2024.00.00.000.