

# Elaboration of undoped ZnO nanowires for use as acetone gas sensors

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**Abstract:** The objective of our work is to provide an advantage for designing new, more efficient sensors using undoped ZnO nanowires. Nanostructures based on ZnO have demonstrated improved sensor performance, thanks to their excellent chemical and thermal stability, as evidenced by their high melting temperature. We have utilized the Schottky defect model to simulate the behavior of free carriers in ZnO semiconductors. Additionally, we have investigated the theoretical model of oxygen molecule adsorption and desorption. Furthermore, we have examined the adsorption of reducing gases, with acetone gas being used as an example. By employing the Comsol software, we have discovered that the solid-gas interaction is significantly reduced at a temperature of 295 °C for ZnO nanowires compared to bulk ZnO, which typically requires a temperature of 500 °C. This reduction can be attributed to the predominant behavior of the side surfaces (101 $\bar{0}$ ) in ZnO nanostructures, as well as the lower activation energy of these surfaces compared to the (0002) surfaces. These ZnO nanowire nanostructures provide numerous active and thermodynamically favorable surfaces for the adsorption of reducing gases. The simulation method using Comsol is one of the means to achieve improved design and offer optimal device operation.

**Keywords :** semiconductor ; ZNO ; Nanostructures

## 1. Introduction

Natural occurrences of ZnO are commonly found in ruby-red minerals, whereas artificially synthesized ZnO appears colorless or white [1]. It finds applications in diverse fields such as solar cells, light-emitting diodes, and gas sensors.

Gas sensors play a crucial role in various applications, from environmental monitoring to detecting toxic gases in industries. In recent years, ZnO nanofilms have garnered significant attention due to their unique properties [2], such as high surface area, sensitivity, Our goal is to provide added value to the design of more efficient sensors with a resistance-based configuration using nanostructures. We pursue this objective by developing ZnO nanowires through a hydrothermal method, followed by studying their detection properties. These nanowires are characterized by multiple active surfaces that are thermodynamically favorable for gas adsorption. However, the challenge we face is to find ways to further enhance the sensitivity of ZnO nanowires towards acetone by exploring configuration modifications.

## 2. Materials and Methods

### 2.1. Growth of ZnO nanostructures

ZnO nanowires have a significant impact in diverse domains including environmental monitoring, security, and healthcare. They are widely employed for manufacturing gas sensors, pressure sensors, and humidity sensors due to their exceptional

characteristics. Their remarkable specific surface area and heightened sensitivity enable them to detect minute concentrations of gases and chemical compounds [3].

## 2.2. Practical Realization

There are several methods commonly used for growing ZnO nanowires in this part we interest about among various synthesis methods, chemical bath deposition (CBD) stands out as a promising technique for the fabrication of ZnO nanowires.

The CBD method presents a simple and cost-effective approach for synthesizing ZnO nanowires, making it highly attractive for large-scale production[4]. This parts aims to delve into the details of the CBD technique for the elaboration of ZnO nanowires, focusing on the crucial parameters and their influence on the growth process.

## 2.3. Solution Preparation

The CBD process begins with the preparation of a chemical solution containing ZnO precursors. This section discusses the selection of precursors, solvent choice, and their concentrations.

We utilize a fixed reaction medium consisting of an equimolar mixture at a concentration of 0.3 mol/L of zinc nitrate ( $Zn(NO_3)_2$ ) and HMTA (hexaméthylènetétramine dissolved in deionized water.

## 2.4. Substrate Treatment :

Prior to the deposition of ZnO nanowires, the substrate undergoes a thorough cleaning process to eliminate impurities and establish an optimal surface for nanowire growth. This involves meticulous cleaning steps to ensure a pristine substrate surface. In addition, passivation techniques be utilized seed layer deposition to enhance the nucleation and facilitate the growth of ZnO nanowires on the substrate.

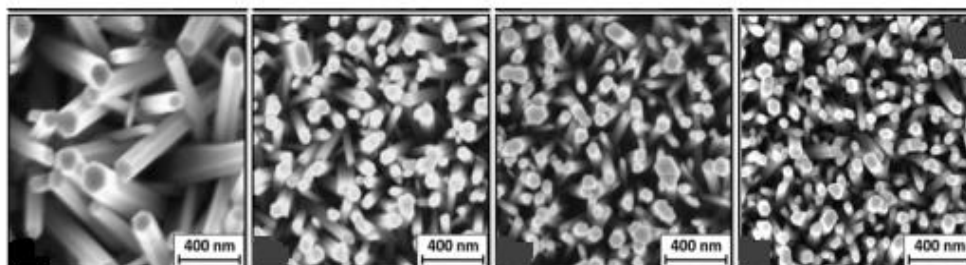
## 2.5. Substract trap:

Seed layer deposition is the initial step in the growth of subsequent layers, providing a foundation or template for desired properties. In the case of ZnO layers deposited through a dipping process using an equimolar mixture of zinc acetate and MEA, their morphology is significantly influenced by the concentration of the solution, the withdrawal speed of the sample, and the number of deposition cycles performed. To investigate the impact of solution concentration, a series of four samples were prepared with concentrations of 0.1, 0.3, 0.5, and 0.7 mol/L . These layers were deposited onto silicon substrates, with a constant withdrawal speed of 10 mm/s. Subsequently, the annealing process was carried out conventionally in two stages: 20 minutes at 300°C, followed by 1 hour at 500°C on a hot plate.

The substrate is immersed in the chemical bath solution, where a chemical reaction takes place to form ZnO nanowires. The  $Zn^{2+}$  ions from the ZnO precursor react with the  $OH^-$  ions present in the solution to form ZnO nuclei on the substrate surface.

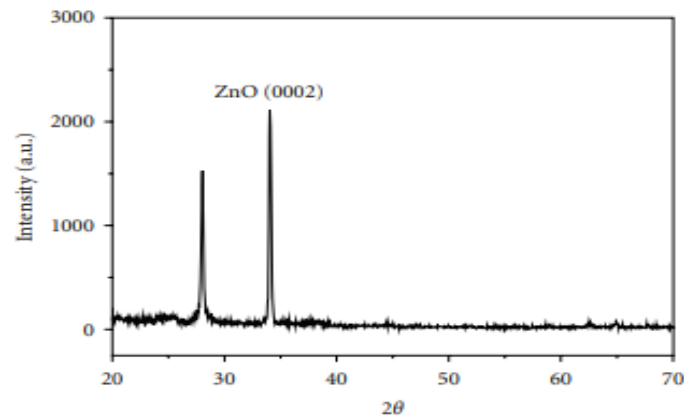
## 3. Results and Discussion

The morphology of the obtained ZnO structures was analyzed using Scanning Electron Microscopy (MEB) (Hitachi type S-2600N, Japan). Each ZnO nanorod was shown to have different formations , Figure describes representative samples of ZnO nanorod arrays, which show large different morphologies.



**Figure 1.** Image MEB presents morphological and variable structural of ZnO nanofils deposited on chemical bath in strictly identical experience condition.

The crystallinity of nanomaterials was followed by X-ray diffraction (DRX) :



**Figure 2.** XRD pattern of the ZnO nanowires.

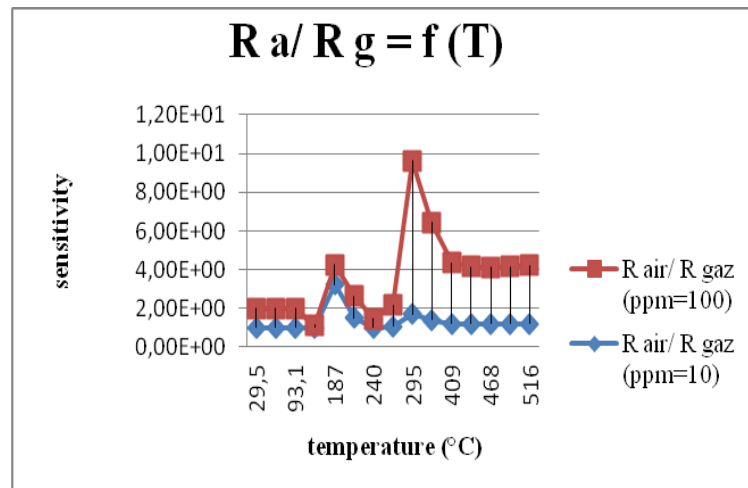
Morphological and structural characteristics of ZNO nanowires deposited in chemical 16 bath :

**Table 1.** Morphological and structural characteristics of ZNO nanowires deposited in chemical bath.

	Average diameter (nm)	Medium length (nm)	Density ( $\mu\text{m}^{-2}$ )
S <sub>1</sub>	115	1400	23
S <sub>2</sub>	77	1060	60
S <sub>3</sub>	60	960	112
S <sub>4</sub>	58	840	100

The morphological and structural properties of ZnO nanowires deposited via chemical bath on layers S1 to S4 are shown in Figure 1 and Table 1 . For all samples, the nanowires exhibit a wurtzite crystal structure and are oriented along the c-axis. As expected, the diameter, length, density, are strongly influenced by the morphology of the seed layer used (see Figure 2).

#### 4. Gas responses of the undoped ZnO :



**Figure 3.** shows the relationship between the responses to 10 ppm and 100 ppm acetone gas and working temperature of undoped ZnO.

The sensitivity was calculated using [5] :  $s = R_a/R_g$

Where  $R_a$  is the film conductance under air and  $R_g$  is the film conductance under gas.

Our sample demonstrated its highest sensitivity at a temperature of 295 °C. As the temperature increased beyond this point, the ZnO nanorowd exposed to acetone gas underwent a noticeable color change,. This change in color is attributed to the adsorption of reduced acetone gas, which leads to an increase in the film's conductance and a shift in the plasmon frequency from the infrared to the visible region [6]. Notably, the electrical properties of pure ZnO are significantly influenced by the adsorption of oxygen on their surfaces. This oxygen adsorption affects the electrical conduction and results in an increase in the resistance of ZnO. Our experimental findings indicate that the specimen exhibits sensitivity to acetone only within the temperature range of 295 °C, as illustrated in Figure 3

## 5. Conclusion

The elaboration of ZnO nanowires through chemical bath deposition is a versatile method that enables control over the morphology, density, and orientation of the nanowires. By varying the growth parameters and experimental conditions, nanowires of different shapes can be formed, including straight nanowires, helical nanowires, and branched nanowires. This flexibility allows for tailoring the nanowires to meet specific requirements and optimize their performance in various applications.

Proper substrate treatment is vital to promote nucleation and control the growth orientation of ZnO nanowires. Surface cleaning methods, surface modification techniques, and seed layer deposition. The influence of substrate properties on nanowire growth is also addressed, emphasizing the importance of substrate selection for specific applications.

## Patents

**Author Contributions:** Contributions Asmaa Zeboudj . Wrote the main manuscript text, prepared the figures and performed all experiments. Saad Hamzaoui . oversaw the project and assisted with the writing of the overall manuscript and zardali mokhter and tadjj asmaa Additional Information Competing Interests: Te authors declare no competing interests.

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**Conflicts of Interest:** The authors declare no conflict of interest.

## References

1. Y. F. Hsu, Y. Y. Xi, A. B. Djurisić, and W. K. Chan, "ZnO nanorods for solar cells: hydrothermal growth versus vapor deposition," *Applied Physics Letters*, vol. 92, no. 13, Article ID 133507, 3 pages, 2008
2. Y. Ishikawa, Y. Shimizu, T. Sasaki, N. Koshizaki Preparation of zinc oxide nanorods using pulsed laser ablation in water media at high temperature *Journal of Colloid and Interface Science*, vol 300, 2, 612-615, (2006)
3. H. He, C. H. Ho, and C. Y. Chen, "Polymer functionalized ZnO nanobelts as oxygen sensors with a significant response enhancement," *Nanotechnology*, vol. 20, no. 6, Article ID 065503, 2009.
4. N.A. Althumairi, I. Baig, T.S. Kayed, A. Mekki, A. Lusson, V. Sallet, A. Majid, A. Fouzri, Characterization of Eu doped ZnO micropods prepared by chemical bath deposition on p-Si substrate. *Vacuum* 198, 110874 (2022)
5. H.X. Liu, D. Cui, M. Li, M. Jiang, *Sens. Actuators B* 114, 301 (2006)
6. X. Wang, J. Song, J. Liu, Z. Lin Wang, *Science* 316, 102 (2007)