# Acetone gas sensor properties based on ZnO nanorod arrays synthesis by MA-CBD

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**Abstract:**

In present research, ZnO nanorod arrays have been synthesizedsuccessfully by microwave assisted chemical bath deposition (MA-CBD) method on $SiO_2$ substrate.Structural and morphological properties were performing by XRD and FESEM, which prove the quality of prepared ZnO nanorod arrays. Gas sensing measurements for the resulting ZnO nanorod arrayshave been made by means of data acquisition system. The measurements show high sensitivity toward acetone vapor at different working temperatures.

**Keywords:** : ZnO nanorod arrays, Acetone gas sensor, MA-CBD.

# خصائص مُتحسس غاز الأسيتون المبنّي على أساس تحضير مصفوفة من القضبان النانويه لأُكسيد الخارصين بواسطة طريقة المايكروويف-الترسيب الكيميائي

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**الخلاصة:**

في هذا البحث، مصفوفة قضبان الخارصين النانوية تم تحضيرها بنجاح باستخدام طريقة الترسيب الكيميائي المعزز بموجات المايكرويف على قاعدة السيلكون اوكسايد. الخواص التركيبية والسطحية درست باستعمال جهاز حيود الاشعة السينية والمجهر الالكتروني الماسح والتي اظهرت جودة القضبان النانوية المحضرة. قياسات تحسسية الغاز لاوكسيد الخارصين المنتجة جمعت بواسطة نظام ادخال البيانات المعتمد على المقياس المتعدد Fluka 8808a المسيطر عليه بواسطة برنامج Labview . القياسات اظهرت حساسية عالية تجاه غاز الاسيتون عند درجات حرارة قياس مختلفة.

**الكلمات المفتاحية:** مصفوفة القضبان النانويه لأكسيد الخارصين، متحسس غاز الأسيتون، طريقة المايكروويف-الترسيب الكيميائي.

## 1. Introduction

Recently, acetone material can be considered as one of the most important volatile organic compounds (VOCs), has been used in many industries as a solvent. Due to high flammable nature of acetone vapor, the detection of the leakage of this volatile gas becomes essential for safety. Researchers made many efforts for sensing these organic gases using solid-state materials as sensors. Metal oxide semiconductors (MOSs) like $SnO_2$, ZnO, and $TiO_2$ are excellent sensors for VOC gases due to reliable sensitivity[1], Low-power consumption[2], high response time, and simple fabrication process[3, 4]. Among these materials, ZnO, with their unique properties such as wide direct band gap of 3.37 eV, and high excitation binding energy of 60 meV[5], is offering suitable parameters for VOC sensing applications. Furthermore, sensing properties of ZnO nanostructured material strongly depend on their shape, size, and morphology of the materials. ZnO such as nanorods; offers the above such requirements[6]. ZnO nanorods can be synthesis using many techniques such as chemical vapor deposition (CVD)[7], thermal evaporation, sputtering[8], molecular beam epitaxy (MBE)[9], Screen printing, electrospinning [10] and chemical bath deposition (CBD)[11] etc. CBD is one of the most significant current synthesis methods for preparation of ZnO nanostructure material due to low cost and low temperature. In this work, microwave heating has been used in a CBD reactor to grow high quality ZnO nanorods arrays. In addition, acetone gas sensing has been investigated for different working temperatures.

## 2. Experiment

Zinc oxide nanorods arrays have been grown on $SiO_2$ substrate using two chemical steps as reported in our previous researches. In brief, ZnO-PVA nanocomposites seed solution material was synthesized by complex aqueous solution of zinc chloride ($ZnCl_2$) through drop wise it in aqueous solution of polyvinyl alcohol (PVA) at 80℃. After that, the seed solution was spin coated on a cleaning$SiO_2$ substrate at 3000 rpm for 30 s. This substrate then was annealed at 380 ℃ for 2 hours. The second step had been done by transferred seeded substrate to another solution contain equal molarities (0.1M) of an aqueous solution of zinc nitrate hexahydrate ($Zn(NO_3)2.6H_2O$) and hexamethylenetetramine ($C_6H_{12}N_4$). The beaker then was placed inside the microwave oven for 2 h at 90℃. Finely, the substrate was washed with DI water followed with ethanol to remove the remaining salt.

Structural properties and their morphology of the ZnO nanorods were performed using X-ray diffraction (XRD) (X'Pert PRO MRDPW3040, PANalytical, Almelo, The Netherlands) and Field-Emission Scanning Electron Microscopy (FEI).

The Acetone vapor sensing characteristics were investigated using home built gas sensor system connected to data acquisition (DAQ) system based on modified LabView software with Fluke 8808a multi-meter. This system is showing in Fig.1. The concentration of acetone vapor was calculated according to the following equation [12]:

$$C = \frac{\frac{(\boldsymbol{P} * \times \boldsymbol{L})}{(\mathbf{760} - \boldsymbol{L})}}{\left(\frac{(\boldsymbol{P} * \times \boldsymbol{L})}{(\mathbf{760} - \boldsymbol{L})}\right) + L + L *} \quad (1)$$

Where L and L* are bubbler gas flow rate and dilute gas flow rate (in sccm), respectively, and P* is the vapor pressure of acetone which is 2500 Sccm (Slandered centimeter cubic per minute) at room temperature.

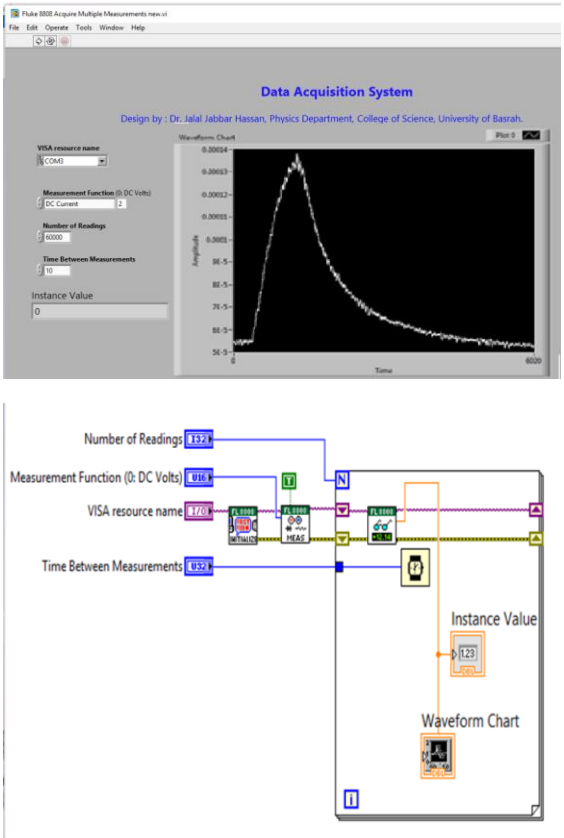


**Fig.1: Block diagram of data acquisition based on modified Labview and Fluke**

## 3. Result and Discussion:

### 3.1 Characterization of Gas-Sensing Materials

X-ray diffraction pattern of ZnO nanorod arrays in Fig.2 and Table 1 show the typical major peak positions that were very well matched to wurtzite structure of ZnO powder (PDF-ICDD 04-006-1673)[13]. FESEM image of Fig. 3 displays the morphology of ZnO nanorod arrays, which reveal clear hexagonal structure with diameters of less than 200 nm with high distribution on entire$SiO_2$ substrate surface. The image also shows clearly the nanorods entanglement and the formation of nano-contacts between these nanorods. These contacts play an important role in gas sensing of ZnO devices due to formation of boundary regions of depletion charge region at these contact points.

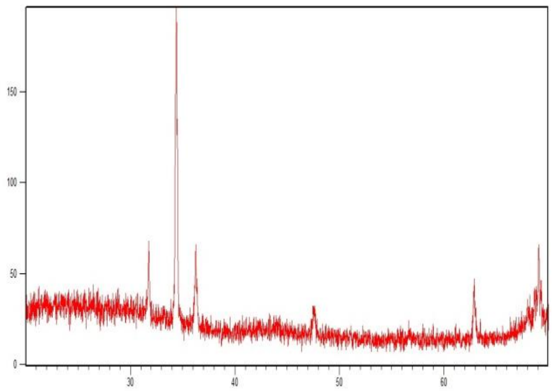


**Fig.2: X-ray diffraction pattern for ZnO nanorod arrays grown on SiO2 substrate**

**Table 1. XRD data results**

| Pos. [°2Th.] | FWHM [°2Th.] | d-spacing [Å] | Rel. Int. [%] |
|---|---|---|---|
| 31.7609 | 0.0886 | 2.81744 | 21.69 |
| 34.3986 | 0.0787 | 2.60719 | 100.00 |
| 36.2569 | 0.0689 | 2.47772 | 24.67 |
| 47.5689 | 0.2362 | 1.91159 | 7.77 |
| 62.8806 | 0.1574 | 1.47800 | 16.12 |
| 69.0842 | 0.1200 | 1.35852 | 25.07 |
| 69.2848 | 0.1080 | 1.35845 | 12.78 |

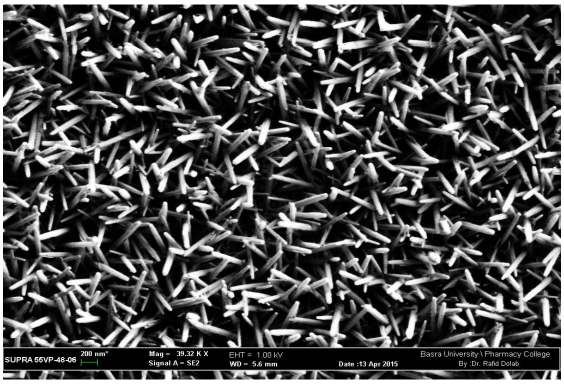

**Fig.3: FESEM image of ZnO nanorod arrays grown on $SiO_2$ substrates**

### 3.2 Gas Sensing Properties

Two main approaches could attribute the enhancing of acetone sensitivity in nanostructures semiconductor metal oxide. The first approach is related to the diameter of ZnO nanorods that consider the important parameter, which determined the sensitivity of ZnO especially in the form of nanorods. In addition, this parameter is directly connected to depletion thickness (space charge region) that formed on the surface of ZnO nanorods due to adsorption of oxygen species [14, 15]. The second approach is the formation of nano-contacts between nanorods networks which plays a key factor to enhance the sensing properties of ZnO nanorod arrays[14]. In the case of VOCs exposure, these potential barriers at contact points between nanorods and the depletion thickness of nanorods will determine strongly the amount of electric current passing through these nanorods. Therefore, these parameters could be a major factor, if not the only one, causing enhancement in the sensitivity of the ZnO nanorod arrays network. The sensing performance of ZnO nanorod arrays for acetone gas is shown in Fig.4 and Fig.5. The sensitivity towards acetone gas is defined as variation of current upon exposure to sensing gas and can be written as[13]:

$$S=((I_{gas}-I_o)/I_o)\times 100\% \qquad (2)$$

Where $I_{gas}$ and $I_0$ are the currents when VOC gas is ON and OFF, respectively.

Accordingly, the sensitivity toward acetone vapor was clearly increased with increasing working temperature as seen in Fig.4 and Fig.5 for low and high working temperatures, respectively [16]. The graphs show that there was a sharp rise in response for acetone vapor with response and recovery time decreased with increasing working temperature, which can be attributed to increase in kinetic energy of target gas. Moreover, In Fig.4 (low-temperature) the sensitivity was low compared with Fig.5 (high Temperature), due to presence only $O_2^-$ ions on the surface of ZnO nanorods, which resulted from the following reaction at low temperature [17]:

$$O_2(\text{gas}) + e^- \longrightarrow O_2^- \qquad (3)$$

As seen from the above equation, there is only one electron associate with molecular oxygen at low temperature. While in high working temperature, two types of oxygen species are taking part on the surface of ZnO nanorods as described in the following equations[17]:

$$\frac{1}{2}O_2 + e^- \longrightarrow O_{ads}^- \qquad (4)$$

$$\frac{1}{2}O_2 + 2e^- \longrightarrow O_{ads}^{2-} \qquad (5)$$

These oxygen spices make ZnO nanorods surface more compatible to reactive with acetone vapor. Furthermore, one can notice from Fig.5, the optimum temperature for sensing of acetone vapor is 250℃, which shows highest sensitivity of 233% and shorter response and decay times 150, 200 second comparing to other working temperatures.

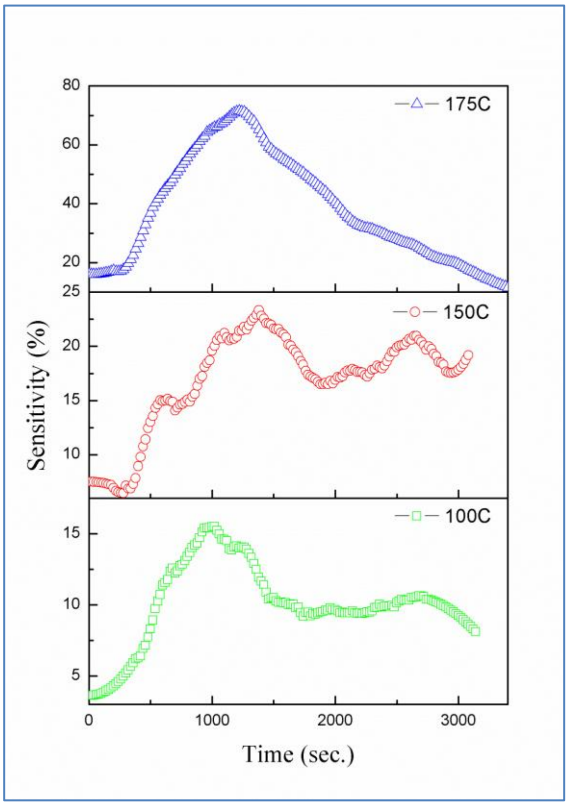


**Fig.4 Sensitivity of ZnO nanorod arrays to acetone vapor at low working temperatures.**

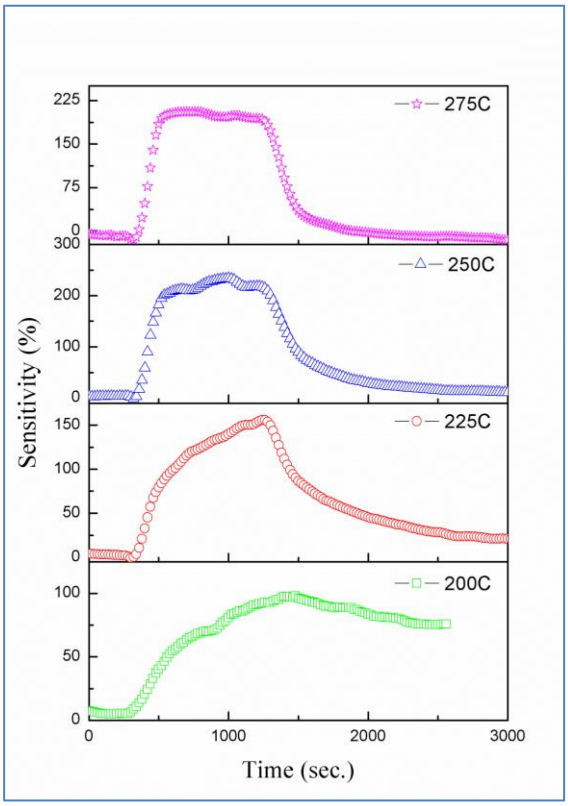


**Fig.5: Sensitivity of ZnO nanorod arrays to acetone vapor at high working temperatures**

## 4. Conclusions

This study has shown that high structural quality ZnO nanorod arrays have been synthesized by the MA-CBD method onto $SiO_2$ substrate that seeded by nanocomposites $Zn(OH)_2$-PVA material. Gas sensing measurement for the resulting ZnO nanorod arrays shows high sensitivity toward acetone vapor at different working temperatures and concentrations. Thus, this result is very important for fabrication an acetone gas sensor.

### Acknowledgements

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