Chapter 4

Synthesis of ZnO nanorods by spray pyrolysis and its gas sensing properties

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4.0 Introduction

An immense research is going on to detect and control various harmful and toxic gases/vapors such as H$_2$S, CO, SO$_2$, NO$_2$, alcohol and hydrocarbons. Semiconductors such as ZnO, In$_2$O$_3$, and SnO$_2$ [1–5] are immensely used as a gas sensors based on change in their electrical conductivity on exposure to the test gases. Appropriate donors can create the electronic defects that enhance the influence of oxygen partial pressure on the conductivity of semiconductor. Various dopants such as Sn, Al, In, Cu, Fe, Ru, Ga have been added in ZnO to explore their applications as gas sensors, piezoelectric devices and in the optoelectrical appliances [6–9]. Detection of combustible and/or toxic gases is one of the rapidly developing fields of sensor technology. The hydrogen sulfide is a toxic and malodorous gas often produced in coal, coal oil or natural gas manufacturing, gasoline, natural gases and sewage. Human exposures to H$_2$S gas at the level higher than 250 ppm are likely to result in neurobehavioral toxicity and may even cause death [10]. Hence, monitor and control over traces of such hazardous gas has become extremely important. Therefore, it is an ongoing need to have H$_2$S sensors with high sensitivity, selectivity, reproducibility, low cost and ease of operation. Different semiconductor oxide based materials such as SnO$_2$, ZnO, In$_2$O$_3$, ZrO$_2$, CeO$_2$, WO$_3$, Fe$_2$O$_3$, have been reported as a H$_2$S sensor in the literature [11–14]. In general, response towards H$_2$S is reported at the higher temperatures; however, there are a few references wherein response at room temperature is also reported [14, 15]. Zinc oxide, the n-type semiconductor having Wurtzite structure with direct energy wide-band gaps of about $\sim 3.4$ eV [16] holds an important status in the field of gas sensor [17, 18]. It is studied in the form of nanostructured, bulk, as well as thin films, of which their thin film form have found wide applications such as transparent electrode for photovoltaic devices [19–21], acoustic wave device [22] and solar cells [23], etc. Various techniques such as spray pyrolysis [17, 24–26], sputtering [27], vacuum arc deposition [28], sol–gel process [29, 30], pulse laser deposition, plasma enhanced chemical vapor deposition [21], spin coating and dip coating have been implemented for the deposition of undoped and doped ZnO thin films. Among these, spray pyrolysis is a simple and inexpensive technique having ease to incorporate various materials, reproducibility, high growth rate and mass production capability for uniform coatings.
Many studies have been done over about three decades on chemical spray pyrolysis (SP) processing and preparation of thin films, since the pioneering work by Chamberlin and Skarman [1] in 1966 on cadmium sulphide (CdS) films for solar cells. Thereafter, due to the simplicity of the apparatus and good productivity of this technique on a large scale it offered a most attractive way for the formation of thin films of noble metals, metal oxides, spinel oxides, chalcogenides and superconducting compounds. Despite its simplicity, SP have a number of advantages. (a) It offers an extremely easy way to dope films with virtually any element in any proportion by merely adding it in some form to the spray solution. (b) Unlike closed vapor deposition methods, SP does not require high quality targets and/or substrates nor does it require vacuum at any stage, which is a great advantage if the technique is to be scaled up for industrial applications. (c) The deposition rate and the thickness of the films can be easily controlled over a wide range by changing the spray parameters, thus eliminating the major drawbacks of chemical methods such as sol-gel which produces films of limited thickness. (d) Operating at moderate temperatures (100-500°C), SP can produce films on less robust materials. (e) Unlike high-power methods such as radio frequency magnetron sputtering (RFMS), it does not because of local over-heating that can be detrimental for materials to be deposited. There are virtually no restrictions on substrate material, dimension or its surface profile. (f) By changing composition of the spray solution during the spray process, it can be used to make layered films and films having composition gradients throughout the thickness. (g) It is believed that reliable fundamental kinetic data are more likely to be obtained on particularly well characterized film surfaces, provided the films are quiet compact, uniform and that no side effects from the substrate occur. SP offers such an opportunity.

In the past decade, one-dimensional (1D) nanostructures, such as carbon nanotube [31, 32], ZnO [33, 34], In$_2$O$_3$ [35, 36], and SnO$_2$ [37, 38] have attracted much interest because of their potential applications in many fields and theoretical importance. Until now, the main efforts have been made on the preparation of 1D nanostructure materials. Recently, gas sensors based on single carbon nanotube [39], SnO$_2$ nanowire [40] and In$_2$O$_3$ nanowire [41] were reported. These sensors have better sensing performance, but it is difficult to obtain single nanowire and to fabricate this kind of device in large quantities. Thick film sensors based on ZnO nanowires were reported
to have good gas-sensing properties by Wan et al. [42], but it is not easy to fabricate ZnO nanowires by an evaporation method. As per knowledge, there are very few reports about the H$_2$S sensing properties of ZnO nanorods up to now. In this work, we fabricated thin film sensors based on ZnO nanorods, which were prepared by a spray pyrolysis method and investigated their gas-sensing properties. The thin film sensors showed a large response to H$_2$S when operated at different temperatures.

4.1 Experimental procedure

4.1.1 Preparation of spraying solutions

All the chemicals used in the work were of analytical grade. The chemicals such as zinc acetate dihydrate, methanol (A.R.) were used without further purification. Zinc acetate dihydrate was dissolved in the mixture of methanol (10 ml) and double distilled water (5 ml) to obtain 0.1 M zinc acetate solution. Such solution was used as precursor solution for synthesis of ZnO thin films.

4.1.2 Substrate Cleaning

The substrate cleaning is very important in the deposition of thin films. Commercially available alumina slides with a size of 25mm×25mm×1mm were washed using soap solution and subsequently kept in hot chromic acid and then cleaned with deionized water followed by rinsing in acetone. Finally, the substrates were ultrasonically cleaned with deionized water for 20 min and wiped with acetone and stored in a hot oven.

4.1.3 Details of spray pyrolysis system

The schematic experimental set up of the spray pyrolysis system which is built in the laboratory as shown in Fig. 4.1 (a, b). It consists of spray gun with nozzle, substrate heater, automatic temperature control unit, air compressor, pressure regulator, thermocouple, stepper motor with controller and power supply. The heater is a stainless steel block furnace electrically controlled by an automatic temperature controller unit to attain the required substrate temperature to an accuracy of ± 2 °C. The resulting temperature on the surface of the substrate is measured with a chromel-alumel thermocouple. Hazardous fumes evolved during the thermal decomposition of the precursor are given out an exhaust system attached to the spray pyrolysis unit. The spray nozzle is made up of borosil glass having a different bore diameter (viz. 0.1 mm,
Due to the air pressure of the carrier gas, a vacuum is created at the tip of the nozzle to suck the solution from the tube after which the spray starts. The spray nozzle is fixed at an appropriate distance from the substrate. The precursor solution was sprayed on to the substrate in the air as small drops and around a high temperature zone, where thermal decomposition and possible reaction between solutions occur, through compressed air, which is used as carrier gas with a flow rate controlled through the air compressor regulator.

To achieve uniform deposition the moving arrangement has been used. For this substrate is kept stationary, while the nozzle is free for to and fro motion with mechanical moving arrangement as stepper motor has been advantageous, so we do not have to spend energy moving the table with the hot plate and all electrical connections. The nozzle system is very lightweight with easy slider trolley attached. The spraying system and heater are kept inside a metallic chamber of size 60×60×60 cm$^3$. The inner surface of the box is painted by epoxy liquid, to reduce the heat loss through the surface.

Fig. 4.1 (a): Schematic representation of the spray system.
4.1.4 Kinetics in thin film deposition

The deposition process needs fine droplets to react on the heated substrate, owing to the pyrolytic decomposition of the solution. The hot substrate provides the thermal energy for the thermal decomposition and subsequent recombination of the constituent species. In many cases large droplets of the solution do not vaporize before reacting to deposit on the substrate. They hit the surface and form a powdery deposit. If it strikes at a high enough velocity, the droplet will splatter and form a dispersed powdery layer. As mentioned above, the droplet cannot be completely vaporized before it hits the surface and for this reason, film growth cannot occur. The influence of forces which determine both the trajectory of the droplets and evaporation were examined and a film growth model was proposed. Fig. 4.2 shows the types of trajectories that are expected to occur in the spraying of a solution on hot glass substrate.

It is reported that the behavior of precursor drops that undergo three major steps during the course of spray pyrolysis: (a) drop size shrinkage due to evaporation, (b) conversion of precursor into oxides, and (c) solid particle formation. The particle formation may involve two mechanisms: intraparticle reaction (conventional one-
particle-per-drop mechanism) and gas-to-particle conversion [43]. In the one particle-per-drop mechanism, each droplet is regarded as a micro reactor and converts into one solid particle when it travels towards substrate. In contrast, gas-to-particle conversion occurs when the precursor is volatile and is transported across the particle-gas interface [43, 44].

![Diagram](image)

**Fig. 4.2:** Kinetics in thin film deposition.

The phenomenon for the preparation of a metal oxide thin film depends on surface hydrolysis of metal chloride on a heated substrate surface in accordance with the equation [45],

$$XCl_m + nH_2O \rightarrow XO_n + mHCl,$$

where X is the metal such as Zn, Sn, In etc of the oxide films.

### 4.1.5 Preparation of ZnO Thin Films

As prepared precursor solution of zinc acetate dihydrate (0.5M) was sprayed, through a glass nozzle of 0.1mm bore diameter, over a hot glass substrate by means of air as a carrier gas so as to reach a substrate in the form of very fine droplets. Prior to deposition the glass substrate (75mm×25mm×1.2 mm), was cleaned by an ultrasonic cleaner to make the surface hydrophilic. The glass substrate kept at a temperature of 350°C. The spray rate of 5 mL/min. was maintained using flow meter and air compressor regulator. The distance between spray nozzle and substrate was fixed at 25cm. During spray pyrolysis process, when precursor solution droplets arrive close to the preheated substrates, the droplets undergo thermal decomposition, which results
into the highly adherent zinc oxide film formation. During the pyrolytic process, following reaction takes place

\[
\begin{align*}
\text{Zn(CH}_3\text{COO)}_2 + 2\text{CH}_3\text{OH} & \rightarrow \text{Zn(OH)}_2 + 2\text{CH}_3\text{COOCH}_3 \\
\text{Zn(OH)}_2 & \rightarrow \text{ZnO} + \text{H}_2\text{O}↑
\end{align*}
\]

The as-deposited films were subjected to post deposition annealing at 500 °C for 1 h in air to obtain highly uniform crystalline films. Simultaneously 10 substrates (2.5 cm × 2.5 cm) in a batch were deposited by spray pyrolysis technique. The various process parameters in the film deposition are listed in Table 4.1.

**Table 4.1:** Process parameters for the spray deposition of the films.

<table>
<thead>
<tr>
<th>Spray parameters</th>
<th>Optimum value/item</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nozzle</td>
<td>Glass</td>
</tr>
<tr>
<td>Nozzle–substrate distance</td>
<td>25 cm</td>
</tr>
<tr>
<td>Zinc acetate solution concentration</td>
<td>0.1 M</td>
</tr>
<tr>
<td>Solvent</td>
<td>Methanol and distilled water</td>
</tr>
<tr>
<td>Solution flow rate</td>
<td>5 ml/min</td>
</tr>
<tr>
<td>Carrier gas</td>
<td>Compressed air</td>
</tr>
<tr>
<td>Substrate temperature</td>
<td>350 °C</td>
</tr>
</tbody>
</table>

4.2 Characterizations of ZnO thin films

The optical absorbance of the films was measured using spectrophotometer (UV-visible-2450 spectrophotometer, Shimadzu) in the wavelength range 300-700 nm. The crystalline structure of the thin films was confirmed by using X-ray powder diffraction (BRUKER D8 Advance) with CuKα = 0.15418 nm radiation in the range of 20°–80°, and field emission scanning electron microscopy (FESEM). The transmission electron microscopy (TEM, PHILIPS EM 200 Make) and selected-area electron diffraction (SAED) were obtained. The gas sensing properties were measured by the static gas sensing measurement system explained elsewhere [46].

4.2.1 Structural properties of ZnO the films

4.2.1.1 X-ray diffraction analysis (XRD)

The XRD spectra of the synthesized ZnO nanorods thin film is shown in Fig. 4.3 and the results indicate that the ZnO material has a nanocrystalline structure and it grows with hexagonal Wurtzite- type. The main significant peaks for ZnO were found
to be (100), (002), (101), (102) and (110). The crystallite size of the ZnO was determined from (101) diffraction peak using Scherrer formula and the average crystallite size was found to be 22.11 nm.

![XRD pattern of ZnO thin film.](image)

**Fig. 4.3:** XRD pattern of ZnO thin film.

### 4.2.1.2 Surface Morphology of the films by FESEM

Fig. 4(a-d), shows the FESEM images of ZnO nanorods thin films with different magnifications. It consists of large number of nanorods sizes ranging from 20 nm to 80 nm leading to high porosity and large effective surface area available for the adsorption of oxygen species. The nano hexagonal shaped rods were deposited symmetrically and the plane (00-01) faceting.

![FESEM images of ZnO nanorods thin films](image)

(a) ![FESEM image](image) (b) ![FESEM image](image)
4.2.1.3 Elemental analysis by EDAX

EDAX spectra for ZnO thin film is shown in Fig. 4.5. Theoretically expected mass % of Zn and O in ZnO are 80.3 and 19.7 respectively. Observed elemental composition of Zn and O is shown in Table 4.2. It is seen that ZnO thin film is nonstoichiometric in nature.

![EDAX spectra for ZnO thin film](image)

**Fig. 4.5:** EDAX spectra for ZnO thin film

**Table 4.2:** Elemental composition of ZnO thin film.

<table>
<thead>
<tr>
<th>Element</th>
<th>Mass %</th>
<th>Atomic %</th>
</tr>
</thead>
<tbody>
<tr>
<td>O</td>
<td>21.78</td>
<td>65.58</td>
</tr>
<tr>
<td>Zn</td>
<td>78.22</td>
<td>34.42</td>
</tr>
<tr>
<td>Totals</td>
<td>100.00</td>
<td>100.00</td>
</tr>
</tbody>
</table>

4.2.1.4 Microstructural property by TEM and SAED pattern

TEM images for ZnO nanopowder obtained by scratching the thin film are shown in Fig. 4.6(a-c) and the corresponding selected area electron diffraction (SAED) pattern in Fig. 4.6(d), respectively. The morphology and microstructure of nanorods
films were investigated from TEM images. All the samples were scanned in all zones before the picture was taken. The micrographs showed that the grains were nearly hexagonal rod in shape and the grain size distribution was in the range from 19 to 41 nm. The SAED pattern (Fig. 4.6 (d)) reveals that the rods are of single crystalline in nature. All diffraction rings can be perfectly attributed to hexagonal wurtize ZnO growing along the [0001] direction. This is consistent with the XRD and FESEM images.

![TEM images of ZnO nanorods](image)

**Fig. 4.6 (a-d):** TEM images of ZnO nanorods.

### 4.2.1.5 Thickness measurements

Film thickness was measured by using a micro gravimetical method [48] (considering the density of the bulk zinc oxide). The films were deposited on clean glass slides whose mass were measured initially. After the deposition the substrate was again weighted, determining the quantity of deposited ZnO. Measuring the
surface area of the deposited film, taking account of ZnO specific weight of the film, thickness (t) was determined using the relation:

$$t = \left( \frac{M_{ZnO}}{A \cdot \rho} \right) \times 10^4 \mu m$$  \hspace{1cm} (4)

where A is the surface area of the film [cm$^2$], $M_{ZnO}$ is the quantity of the deposited zinc oxide and $\rho$ is the specific weight of ZnO. The thickness of the film was 0.284 µm.

4.2.1.5 **Optical properties of the ZnO thin film by UV-vis spectroscopy**

Absorption spectra for ZnO thin film are shown in Fig. 4.7. The absorption at higher wavelengths in the visible region is low and at wavelength 300-350 nm an intense absorption can be seen.

![Absorption spectra](image)

**Fig. 4.7:** Variation of absorbance with the wavelength (λ) nm for ZnO nanorod thin film.

The value of absorption coefficient ($\alpha$) is of the order of $10^4$ cm$^{-1}$. The band gap of the film was calculated by plotting $(\alpha \cdot h \nu)^2$ vs $h \nu$ using the relation,

$$\alpha h \nu = A(h \nu - E_g)^n,$$  \hspace{1cm} (5)

where $\alpha$ is absorption coefficient, A is constant, $E_g$ is the optical band gap energy, $h \nu$ is the photon energy and $n$ is constant. The value of $n$ is 1/2 or 2 depending on presence of the allowed direct and indirect transitions. Fig. 4.8 shows the plots of $(\alpha h \nu)^2$ versus $h \nu$ for ZnO thin film. The nature of the plots suggests direct interband
transition. The band gap is determined by extrapolating the straight line portion of the plot to the energy axis [49]. The intercept on energy axis gives the value of band gap energy for ZnO nanorod thin film which is 3.6 eV.

![Plot of the $(\alpha h\nu)^2$ verses photon energy $(h\nu)$](image)

**Fig. 4.8:** Plot of the $(\alpha h\nu)^2$ verses photon energy $(h\nu)$

### 4.2.2 Electrical properties of ZnO thin film sensor

#### 4.2.2.1 Fabrication of sensor element

The gas sensing element was designed with a 2.5 cm × 1 cm area. The contacts were made by coating silver paste on thin film surface. The schematic of the gas sensing device is as shown in Fig. 4.9. The gas sensor system developed in the laboratory was employed for characterizing the sensor performance.
4.2.2.2 I-V characteristics

Fig. 4.10 represents I-V characteristics of the ZnO thin film at room temperature. It was clear from the I-V characteristics that the contacts fabricated on the film were Ohmic in nature [50]. The voltage was applied in the range 1V-30V.

![I-V characteristics](image)

**Fig. 4.10:** I-V characteristics of the ZnO thin film.

4.2.2.3 Electrical conductivity

![Log conductivity vs temperature](image)

**Fig. 4.11:** Variation of log (conductivity) with temperature of ZnO thin film.

Fig. 4.11 shows the variation of log (conductivity) with operating temperature. The conductivity of the thin film is observed to be increasing with an increase in the
temperature. The increase in the conductivity with increase in the temperature could be attributed to negative temperature coefficient of resistance and semiconducting nature of ZnO thin film.

4.2.2.4 Thermoelectric power (TEP) measurements

The thermoelectric power (TEP) was measured as a function of temperature in the range between 300 and 425 K. TEP is the ratio of thermally generated voltage to the temperature difference across the semiconductor. Diffusion of thermally generated majority charge carriers occurs from high temperature to the low temperature end, as a result of temperature difference ($\Delta T$). This creates a positive space charge near high temperature end, which sets up an electric field or potential difference thereby giving rise to a thermo electromotive force (e.m.f.) ($\Delta E$). For ZnO material, conduction electrons originate from ionized defects such as oxygen vacancies, rendering n-type conductivity. The variation of the thermo e.m.f. with temperature difference ($\Delta T$) for ZnO thin film is shown in Fig. 4.12.

The rate of increment in TEP is higher in the range of $\Delta T$ from 355 to 375 K and thereafter slowed down. Initial increment is attributed to the increase in mobility of charge carriers and carrier concentration with rise in $\Delta T$. The magnitude of TEP increases with rise in temperature difference ($\Delta T$).

![Graph showing variation of the thermo e.m.f. with temperature difference ($\Delta T$).](image)

**Fig. 4.12:** Variation of the thermo e.m.f. with temperature difference ($\Delta T$).
4.3 Gas sensing performance of the ZnO thin films

4.3.1 Gas response of ZnO nanorod thin films with operating temperature

Gas response of a sensor is defined as the ratio of the conductance change upon exposure to a test gas to the conductance in air. The as prepared ZnO films were tested to various gases such as LPG, CO, CO$_2$, Ethanol, O$_2$, NH$_3$, H$_2$S, H$_2$ and Cl$_2$ at various temperatures ranging from 30$^\circ$C to 450$^\circ$C. It shows maximum response to H$_2$S gas at 50$^\circ$C for 100 ppm gas concentrations. The variation of H$_2$S gas response with operating temperature ranging from 30 to 450 $^\circ$C is shown in Fig. 4.13. The response goes on increasing with the temperature, attains its maximum (50 $^\circ$C) and then decreases with further increase in temperature. It is clear from graph that the optimum operating temperature is 50 $^\circ$C.

![Fig 4.13: The variation of H$_2$S gas response with operating temperature.](image)

4.3.2 Selectivity of ZnO thin films for various gases

The ability of a sensor to respond to a certain gas in the presence of other gases is known as selectivity. The selectivity of ZnO thin film is shown in Fig. 4.14. The sensor showed maximum selectivity to H$_2$S gas against other gases. The figures indicated on the histogram shows the response values of concern gases.
Fig. 4.14: Selectivity of ZnO thin film.

### 4.3.3 Response and recovery time

The time taken for the sensor to attain 90% of the maximum change in resistance upon exposure to the gas is the response time. The time taken by the sensor to get back 90% to the original resistance is the recovery time [51]. The response and recovery profile of the ZnO film to H$_2$S gas is shown in Fig. 4.15. The response time is 4 s and recovery time is 60 s respectively. The faster response time of ZnO thin film would be due to fast mass transfer of gas molecules to and from the interaction regions of the film.

Fig. 4.15: The response and recovery profile of ZnO thin film.
4.3.4 Variation in gas response with H$_2$S gas concentration

![Graph](image)

**Fig. 4.16:** The variation in response with gas concentration of ZnO thin film.

The variation of gas response of ZnO thin film with H$_2$S gas concentration is represented in Fig. 4.16 at 50°C. Each film was exposed to varying concentrations of H$_2$S gas (10–140 ppm). At lower gas concentrations, a monolayer of the gas molecules would be expected to be formed on the surface, which could interact with the surface more actively, giving larger responses. There would be multilayer of gas molecules on the sensor surface at the higher gas concentrations, resulting in saturation in response. The active region of ZnO thin film is from 10 to 100 ppm H$_2$S gas concentrations.

4.3.5 Discussion

Most of the semiconductor oxide gas sensors operate on the basis of the modification of the electrical properties of an active element, which is brought about by the adsorption of an analyte on the surface of the sensor. ZnO nanorods can adsorb oxygen from the atmosphere, both the O$_2^-$ and the O$^-$ species. The adsorption of O$^-$ is the most interesting process in the sensors, because this oxygen ion is the more reactive and makes the material more sensitive to the presence of reducing gases. At relatively low temperature the surface preferentially adsorbs O$_2^-$ and the sensor signal of the material is consequently very small. As the temperature increases, the oxygen will be adsorbed on the surface of the ZnO nanorods (denoted as O$_2$). The
adsorbed oxygen and the surface lattice oxygen (O$_2^-$) of the ZnO nano-rods take part in the oxidation of H$_2$S molecules. Once the oxidation reaction takes place, electrons will enter into the ZnO nanorods, resulting in their decreased resistance. The extremely high surface to volume ratios associated with 1D nanostructures may be the reason why the sensor signal of the ZnO nanorod material increases so much. If the temperature increases too much, progressive desorption of all previously adsorbed oxygen ionic species occurs and the sensor signal decreases.

The gas-sensing mechanism of nanostructured ZnO thin film sensor is interpreted by the resistance change originated from the chemisorbed oxygen on the depletion surface layer, as shown in Fig. 4.17 [52, 53]. Potential barriers on the boundaries of grains reduce the mobility of the carrier, and the band bending on the concentration of free charge carriers take the dominant effect on the sense response. The non-stoichiometry in ZnO acts as electron donors to provide electrons to the conduction band.

**Fig. 4.17:** Schematic presentation of H$_2$S gas sensing mechanism.

When the surface of ZnO thin film is exposed to the air (Fig. 4.17(a)), the oxygen molecules adsorb on ZnO surface and form O$_2^-$ by capturing electrons from the conduction band. When the adsorption of oxygen reaches a certain level, a thick space-charge layer is formed which leads to a decrease of carrier concentration and thus results in a higher resistance. In contrast, when the thin film of ZnO is exposed to reductive gases (Fig. 4.17(b)), for instance, H$_2$S, the reductive gas will react with the adsorbed oxygen species to produce SO$_2$ and H$_2$O, which leads to an increase of
carrier concentration and a decrease of the resistances \[54\]. The mechanism can be explained by several chemical reactions which are shown below:

\[
\begin{align*}
O_2(\text{gas}) & \rightarrow O_2(\text{ads}) \quad (6) \\
O_2(\text{ads}) + e^- & \rightarrow O_2^-(\text{ads}) \quad (7) \\
2H_2S(\text{ads}) + 3O_2^-(\text{ads}) & \rightarrow 2SO_2(g) + 2H_2O + 6e^- \quad (8)
\end{align*}
\]

It can be concluded that ZnO nanorods faceting to plane \([0001]\) and the vacancies form the substituent or interstitial impurity in ZnO crystalline play great role for the improvement of its H\(_2\)S gas sensing performance.

4.4 Conclusions

i) Hexagonal pillar shaped ZnO nanorods with different sizes have been successfully synthesized by spray pyrolysis technique (SPT).

ii) The hexagonal vertically aligned ZnO rods improved the sensing performance to H\(_2\)S gas at lower temperature (50 °C).

iii) The ZnO nanorod based sensor is the most selective to H\(_2\)S gas against the other interfering gasses for 100 ppm gas concentrations.

iv) The response of ZnO nanorods thin film to H\(_2\)S gas is quick (4 s) but it requires more time to recover back (60 s).

v) ZnO thin film has potential in application of room temperature H\(_2\)S gas sensing.
References


