

Modeling of Gas Sensor based on Zinc Oxide Thin Films by Feedback Loop using Operational Amplifier --Manuscript Draft--

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Abstract:	Gas sensing is seeking the attention of both industries and academia because of its wide-ranging application and intrinsic limitations of sensing technologies. Mostly, the gases are sensed due to variation in electrical, optical, acoustic, chromatographic, and calorimetric properties of sensing materials in the influence of various gases but in case of zinc oxide thin film, its resistance varies in influence to reducing gases [1, 2]. Particularly, this article is concerned in modeling durable sensing device using Zinc oxide thin film at low cost and operating within the low potential. To eliminate the temperature dependency for higher sensitivity of the sensor and fabricate cheap, portable, precise, less energy-consuming and durable sensing device, a new electronic model of the sensor was self-designed and analyzed. Monitoring the change in film's resistance, a perfect gas sensor was built. Zinc oxide thin film was synthesized by using the Sol-gel method (Spin coating) and was characterized by XRD and SEM which revealed wurtzite polycrystalline nature of Zinc oxide film with average grain size 17-25 nm. The fabricated film showed a fabulous response to ethanol and methanol vapors. It's the noble electronic model of gas sensing in the current time.
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Manuscript title: MODELLING OF GAS SENSOR BASED ON ZINC OXIDE THIN FILMS BY FEEDBACK LOOP USING OPERATIONAL AMPLIFIER

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Declaration of interests

☒The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Christian Schulz
Editorial Director
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Dear Schulz,

Warm greeting from Patan Multiple Campus and Nepal Academy of Science and Technology (NAST), Nepal. We would like to submit the manuscript entitled “Modeling of Gas Sensor based on Zinc Oxide Thin Films by Feedback Loop using Operational Amplifier” to be considered for publication as an original article in Sensors and Actuators.

Our research is concerned in modeling of gas sensor and we designed an unaccustomed electronic circuit, modeled it theoretically, and then experimentally verified that the circuit performs well by using Zinc oxide thin film as sensing material in the circuit.

We declare that our findings are completely novel till date and no such articles have been published in any of the journals before. Furthermore, we would like to apprise that this manuscript is original, has not been published before and is not currently being considered for publication elsewhere.

We are known that this publication has no conflicts of interest associated and there hasn't been any financial support for this research that could influence its outcomes. As a corresponding Author, I would like to confirm that the manuscript has been read and approved for submission by all the authors.

Sincerely,
Raju Bhattarai

About the revision

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Dear ,

Manuscript entitled **"Modeling of Gas Sensor based on Zinc Oxide Thin Films by Feedback Loop using Operational Amplifier"** had been sent back for second revision. We want to greet heartily the reviewers for their valuable reviews and apologies for inconvenience and commend the following edition as per the reviewer's suggestion for the publication of the article.

Reviewer #4: The suggested corrections have been studied thoroughly and made all the possible corrections and justified their corrections.

Replied: We are thankful to the reviewers.

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 - Upload it to an institutional repository or at a free, open repository such as Zenodo <https://zenodo.org/> , GitHub or equivalent repository.
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Replied: We have uploaded in GitHub.

github.com/raaju1993/Sensor-Data

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Replied: It would be easier to edit if you had marked the particular sentences. Though we have discussed, consulted and tried to simplify almost as possible.

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Raju Bhattarai

Modeling of Gas Sensor based on Zinc Oxide Thin Films by Feedback Loop using Operational Amplifier.

Raju Bhattarai^{*,1}, Ram Bahadur Thapa¹, Deependra Das Mulmi², Rishi Ram
Ghimire¹

Abstract: Nanostructured Zinc oxide thin-film is widely used as a sensing material because of its tunable surface microstructure and wide optical bandgap but synthesizing a film with desired value of resistance and reproducibility of film is challenging, particularly by chemical method. In this work, we showed how a ZnO film of arbitrary resistance can be used as a sensor without application of heat using operational amplifier. Zinc oxide thin film was synthesized by using the Sol-gel method (Spin coating) and was characterized by XRD and SEM which revealed wurtzite polycrystalline nature of Zinc oxide film with average grain size 17-25 nm. In this report, we designed a noble electronic circuit capable of detecting analyte gas molecule even if very small change in film resistance occurs due to the influence of gas molecule. In recently available sensors, the quality of the film degrades over time due to repeated heating and cooling, resulting in a reduced lifetime for the sensor. To address this issue and achieve higher sensitivity, as well as to fabricate an affordable, portable, precise, energy-efficient and durable device, this electronic model offers advantages over classical temperature-dependent sensors.

Keywords: Miniatured sensing device, less energy consuming, noble electronic model.

I. Introduction

Currently, gas sensing is seeking the attention of both industries and academia because of its wide-ranging application in the areas like industrial production (e.g., detection of methane in mines), automotive industry (e.g., detection of pollutant gases from vehicles), medical applications (e.g., electronic noses simulating the human olfactory system), supervision of indoor air quality (e.g., carbon monoxide detection), environmental studies (e.g., monitoring greenhouse gas). Since the last sixty years, researches have been focused on investigation of different types of sensing materials, sensing mechanism and, fabrication techniques of sensing materials. Those researches revealed various fabrication techniques, introduced several sensing materials (e.g., different metal-oxides, polymers) and different approaches of sensing mechanism [1].

Mostly, the gases are sensed by the particular materials due to variation in electrical, optical, acoustic, chromatographic and calorimetric properties of sensing materials in influence of various gases. In case of metal oxide semiconductor thin films, nanotubes and polymers, the electrical property, i.e. resistance of the film, varies due influence of respective gases [2]. By monitoring this change in value of resistance of the film, a perfect gas sensor can be built.

Various nanostructured materials such as thin film, nanowire, nanotube, and nanopowder, composed of different materials including metals, semiconductors, and polymers, are widely utilized in fabricating gas sensors. Among these, metal oxide semiconductor is considered one of the strong candidates for sensors and detectors, with ZnO being particularly promising due to its wide abundance, eco-friendliness, cost-effectiveness, and tunable surface morphology [1]. However, despite being an excellent candidate for gas sensors, ZnO suffers from a serious

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drawback: slow response times, difficulty in maintaining desired resistance and challenges in sensing at room temperature.

To overcome these discrepancies, one needs to modify the synthesis process of the material to achieve a high-quality film with the desired resistance suitable for sensing purposes. In this work, we have designed a simple electronic circuit connected with a ZnO film of arbitrary resistance. This circuit assists in detecting even small fractional changes in the resistance of the film due to the influence of reducing gases using an operational amplifier. This technique has enabled us to avoid the need for advanced and expensive synthesis processes to achieve a desired resistance. This technique can apply to realize a sensor using a film grown by any method and any value of resistance.

Most metal oxide-based gas sensors require maintenance at a specific operating temperature to achieve higher sensitivity. For example, MQ sensors utilize an inbuilt heating system to raise the temperature of sensing material to a range of 200°C to 300°C for effective sensing. These sensors cannot function independently; instead, they must be connected to an Arduino-UNO and cannot be powered by a small battery source alone. Additionally, they require a significant warm-up time to function optimally [3]. Extended use of the sensor film at high temperatures may alter its surface microstructure over time, leading to inconsistencies in sensor performance and potential damage to the film and device. Therefore, operating the sensor at room temperature is preferable to mitigate these issues. Our electronic circuit addresses this challenge by eliminating temperature dependency, resulting in a cost-effective, portable, precise, energy-efficient, and durable sensing device. This approach represents an emerging and highly sought-after technique in gas sensing applications today.

II. Methodology

Gas sensing properties of various metal oxide semiconductors were studied through published journals and variation in resistance of different materials were noted. Different electronic circuits were designed using CircuitMod 2.7 and Online Circuit Simulator and Schematic Editor-Circuit Lab. Then the variation in output of the designed circuit due to change in resistance of the variable resistor (Thin Film) was tabulated and analyzed. For the experimental verification, single coated Zinc Oxide thin films were fabricated using spin coating method.

Fabrication of thin film:

There are more than a dozen of methods: Laser ablation, Physical vapour decomposition, Melt mixing, Sputter deposition, Electric arc deposition, Ion implantation, Precipitation method, Co-precipitation method, Colloidal methods, Sol-gel processing (Spin coating, Dip coating and Spray pyrolysis), Water-oil micro-emulsion method, Hydrothermal synthesis, Solvothermal, Sono-chemical synthesis, Polyol methods, Vapour phase fabrication, etc for thin film fabrication [4, 5]. Because of its simplicity, reliability and accessibility, we found Spin Coating method being feasible within our budget and lab frame too.

Spin Coating is the most preferred technique for the thin film deposition onto flat substrate due to its plainness, low cost, easy doping, low operating temperature and spin and film thickness controllability. A very small amount of coating material is dropped at the centre of the substrate spinning at a constant speed or at rest, and then is rotated at high speed to spread the material uniformly all over the substrate. As soon as, the coating is completed, the

substrate is annealed for the evaporation of the unwanted solvent and deposition of the film. The process is continued until the desired thickness or resistance of the film is achieved [6, 7].

Glass substrates were cut into square pieces (2.5cm x 2.5cm), washed with distilled water then sonicated for 15 minutes with distilled water and Acetone at 70°C then dried in a hot air oven at 100°C. For 0.5 M precursor solution (Solution for pure ZnO thin film), 13.3872 g of Zinc Acetate Dihydrate (ZAD) and 6mL of Diethyl Amine (DEA) added to 120 mL of Ethanol was stirred at 300 rpm for an hour at room temperature. 0.1 mL of precursor solution was spread over the spinning (at 3000 rpm for 30 seconds) substrate in a spin coater and was annealed over the hot plate at 550°C for 15 minutes as illustrated in figure 1.

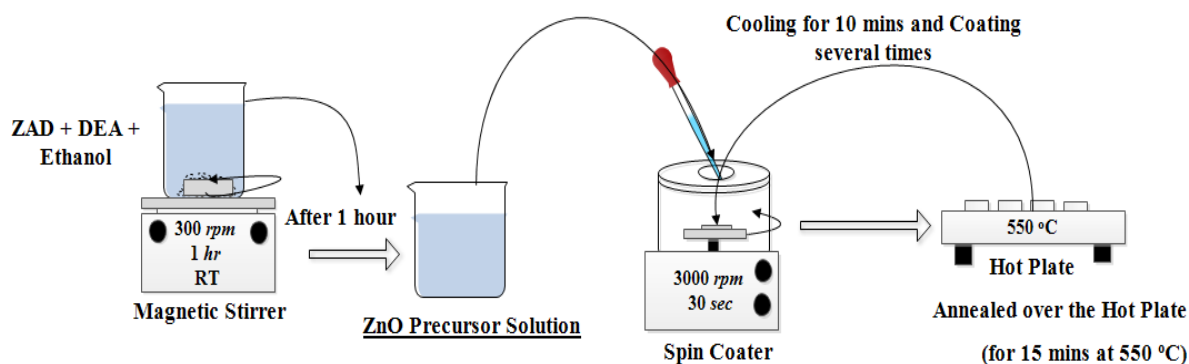


Figure 1: Preparation of ZnO thin film by Spin Coating Method.

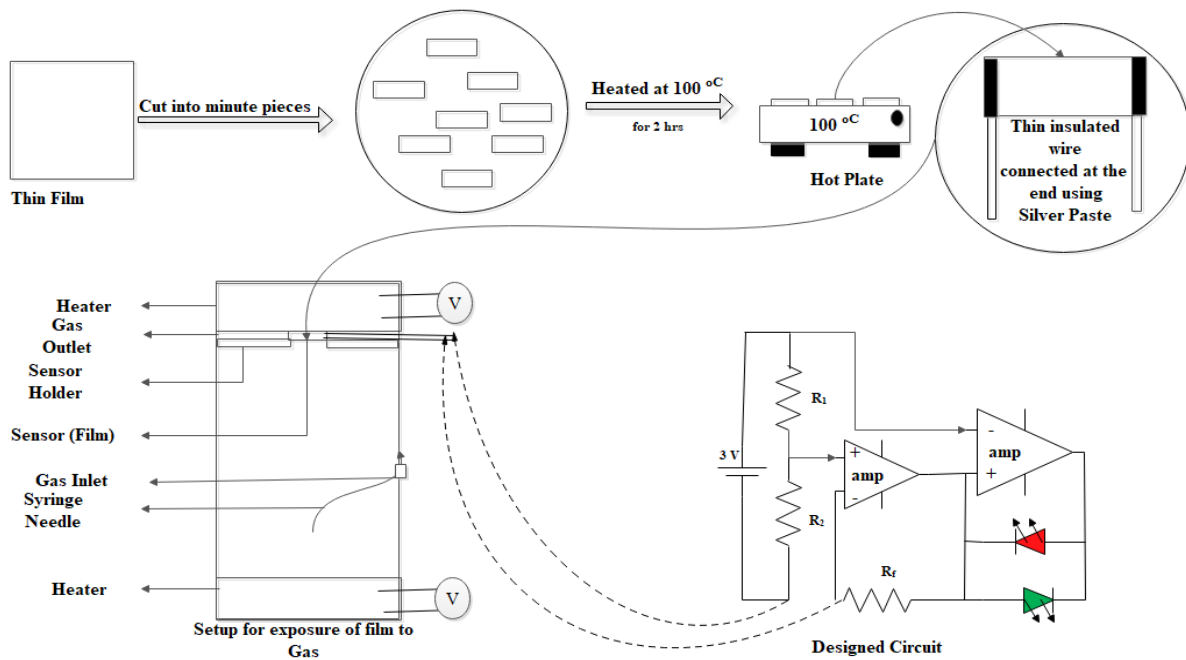


Figure 2: Entire setup for sensing.

The films fabricated were further cut into minute pieces (4 mm x 7 mm) and heated at 100°C for 2 hours. Upon heating, thin insulated wires-conducting at the ends were connected to both the ends of the film using Silver paste. Two heating systems were adjusted at the ends of a cylinder of the volume of about 300 cm³; heater at the top was to monitor the temperature of the film (if necessary) and heater at the bottom was to evaporate liquid (if necessary). This is the way, how we built a setup for the exposure of thin film to gas for sensing purpose. The needle of the syringe was adjusted as shown as in the figure 2 so as to pass gas or drop liquid over the heater. Different concentrations of ethanol and methanol were passed into the chamber and corresponding response of the circuit was observed and noted.

Circuit (Sensor) Designing:

Several electronic circuits were designed using CircuitMod 2.7 and Online Circuit Simulator and Schematic Editor called Circuit Lab. The variation of outputs resulting from changes in resistance of thin film used in the circuit was analyzed. Then the necessary electronic components were soldered onto the PCB board.

Two resistors labelled R_1 and R_2 as shown in figure 3 were connected in series with a 3 V battery. The positive input terminal of first amplifier was linked to the junction of R_1 and R_2 and the negative input terminal was joined to the connecting point of feedback resistor (R_f) and film resistor (R_x). The output terminal of the first amplifier was connected back to its negative input terminal through a feedback resistor and also to non-inverting input terminal of second amplifier as illustrated as in the figure 3. For second amplifier, its inverting input terminal was connected to positive terminal of the battery, positive input terminal was connected to output terminal of first amplifier. Two light emitting diodes (LED), one red and the other green were connected in anti-parallel configuration (anode of red

joined to cathode of green and vice-versa) between the outputs of first and second amplifiers with cathode of red LED connected to output of first amplifier. The seventh pins of both amplifiers were connected to positive terminal of source; fourth pins were grounded, while the first and eighth pins were left floating. Additionally, a burger was connected in series with red LED.

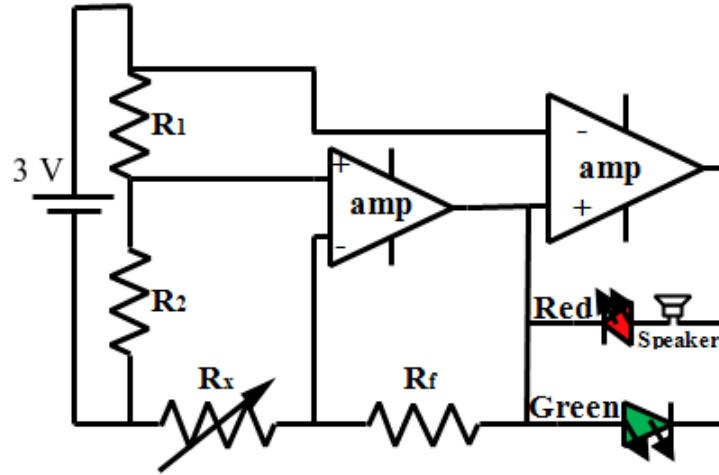
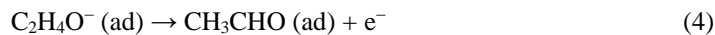
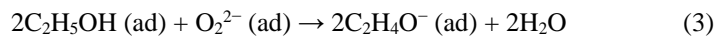
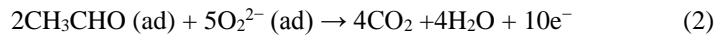


Figure 3: Designed Sensor Circuit where R_x is film resistance.

Also, the configuration works if the both amplifiers and LEDs are flipped with respect to polarity.

Sensing Mechanism:

The detection mechanism of Semiconductor Metal Oxide (SMO) as a sensor is complex and not yet fully understood. Adsorption ability, electrophysical and chemical properties, catalytic activity, thermodynamic stability and the adsorption/desorption properties of the surface of SMO as well yields this complexity [1]. ZnO (n-type semiconductor) thin film surface, when exposed to air, adsorb oxygen molecules to form molecular type adsorbate (O_2 , O_2^-) and dissociative type (O_2^{2-}) adsorbate ions forfeiting electrons from the conduction band, yielding electron-depleted space-charge layer in the grain boundary region which leads to large surface potential barrier and large resistance. The target gas (ethanol/methanol) may undergo dehydration and dehydrogenation and successively oxidized to CO, CO_2 and H_2O , but ZnO being basic oxide, dehydrogenation is favored. The response of the film towards alcohol vapors is dependent on the conversion of alcohol into aldehydes [7, 8].



The release of electrons back to the film enhances the conductivity of the film and deduces the resistance [8]. The oxygen adsorbed onto the film surface traps electrons from the bulk of material forming a potential barrier. When the adsorbed oxygen is replaced by reducing gas molecules the barrier at the grain boundaries decreases consequently reduces the electrical resistance of the film [1]. This reduces potential at the negative input terminal of

the first amplifier which yields change in its output and potential at the positive input terminal of the second amplifier. This change in the value of positive input of the second amplifier changes the polarity of its output from negative to positive and current flows through red LED only. So, only red LED glows and burger beeps.

In the former case, when the film is not exposed to reducing gas, the circuit yields negative output. This causes the red LED to be reverse biased, blocking electron to flow through it while the green LED, being forward biased, allows current flow through it and glows. Once the vapor dissipates, the film promptly resumes its adsorption of atmospheric oxygen, returning to its original state [8]. Consequently, the circuit once again emits a green glow once the film has recovered.

III. Results and Discussion

UV-Vis Spectroscopy:

The optical characterization of the samples was performed in Nepal Academy of Science and Technology (NAST) using UV-Vis spectrophotometer (Cary 60 spectrophotometer, Agilent Technology). The absorbance and transmittance of the films were measured which were further analyzed in figure 4 to calculate the band gap and thickness of the films. For indirect transition, the variation in absorption coefficient with the photon energy obey Tauc's plot method,

$$(\alpha h\nu)^{0.5} = A(h\nu - E_g) \quad (\text{Eq. 1})$$

Where A is a constant, E_g is the optical band gap, h is the plank constant and α is the absorption coefficient. Extrapolation of $(\alpha h\nu)^{0.5} = 0$ yields the optical bandgap energy of the films [9].

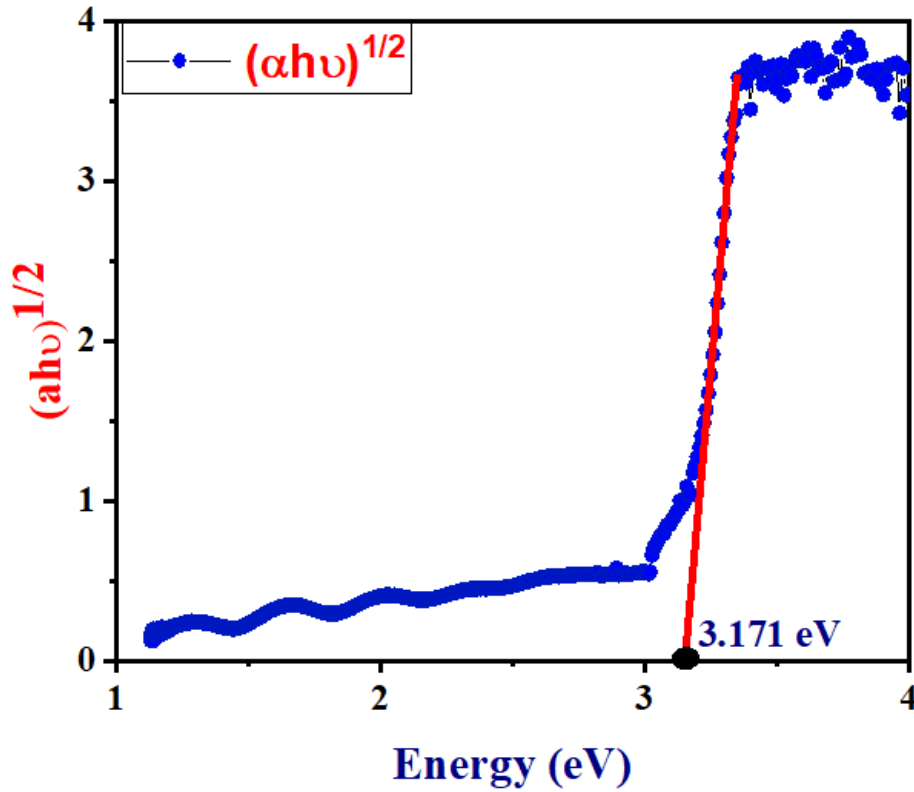


Figure 4: Tauc's Plot for calculation of Energy Bandgap

The bandgap of thin film fabricated by us was found to be 3.171 eV.

X-ray Diffraction (XRD):

The dual natured (behaving as both particle and wave) electromagnetic radiation having high penetration power [6], photon energy within 100 eV- 100 KeV is termed as X-ray. It is a non-destructive technique used for characterizing crystalline substance. This helps in the identification and quantification of the crystalline phase, structure, orientation, composition and defects. Further, it is used to measure the size, strain or micro-strain effects, transparency and electron mobility in thin-films [10]. The structural characterizations of fabricated thin films were analyzed using XRD [Bruker D2 Phaser X-ray diffractometer of CuK α radiation (wavelength: 1.54184 Å)] at 40 KV of operating voltage and current of 40 mA in the 2θ range of 20° - 80° at scanning rate of 15° per minute at NAST, Khumaltar, Lalitpur, Nepal as shown in figure 5. The Debye Scherrer's formula used to calculate the average grain size 'D' is given by,

$$D = \frac{0.9\lambda}{\beta \cos \theta} \quad (\text{Eq. 2})$$

Where, 0.9 is the correction factor, λ is the wavelength of the x-radiation, β is the full width at half maximum (FWHM) of the observed peak and θ is the Bragg's angle [10]. Comparing calculated d-spacings with the standard JCPDS values of card number 36-1451, the observed peaks were indexed. The average crystallite size of ZnO was found to be 20.068 nm using Scherrer's method.

The

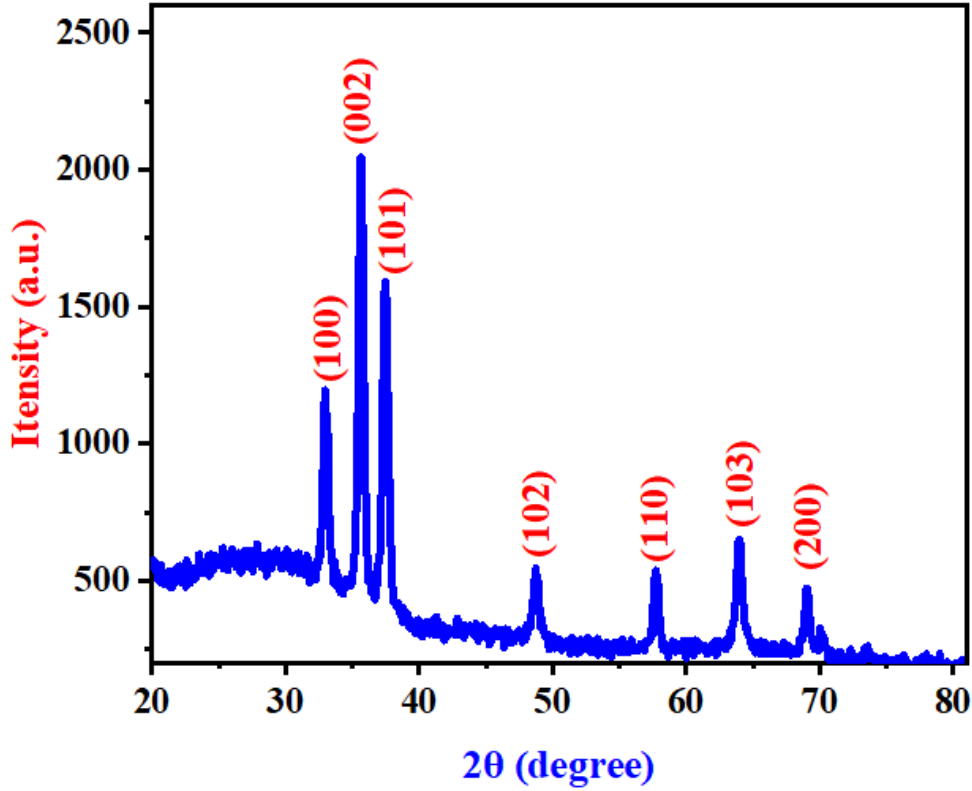


Figure 5: XRD pattern of Pristine ZnO thin film.

The crystallite size of as deposited ZnO thin films were also calculated using W-H plot method using prominent XRD planes then compared with that obtained from Scherrer's formula. The W-H plot is related with the full width half maxima (FWHMs) (β) of XRD peaks and crystallite size (D) through the relation,

$$\frac{\beta \cos \theta}{\lambda} = \frac{1}{D} + \frac{4\epsilon \sin \theta}{\lambda} \quad (\text{Eq. 3})$$

Where, ϵ is the amount of residual strain, θ is the angle of diffraction, λ is the wavelength of X-ray [10]. A graph between $\beta \cos \theta / \lambda$ versus $4 \sin \theta / \lambda$ when plotted and fitted linearly, the reciprocal of the x-intercept gives the average crystallite size [11] and was found to be 17.345 nm.

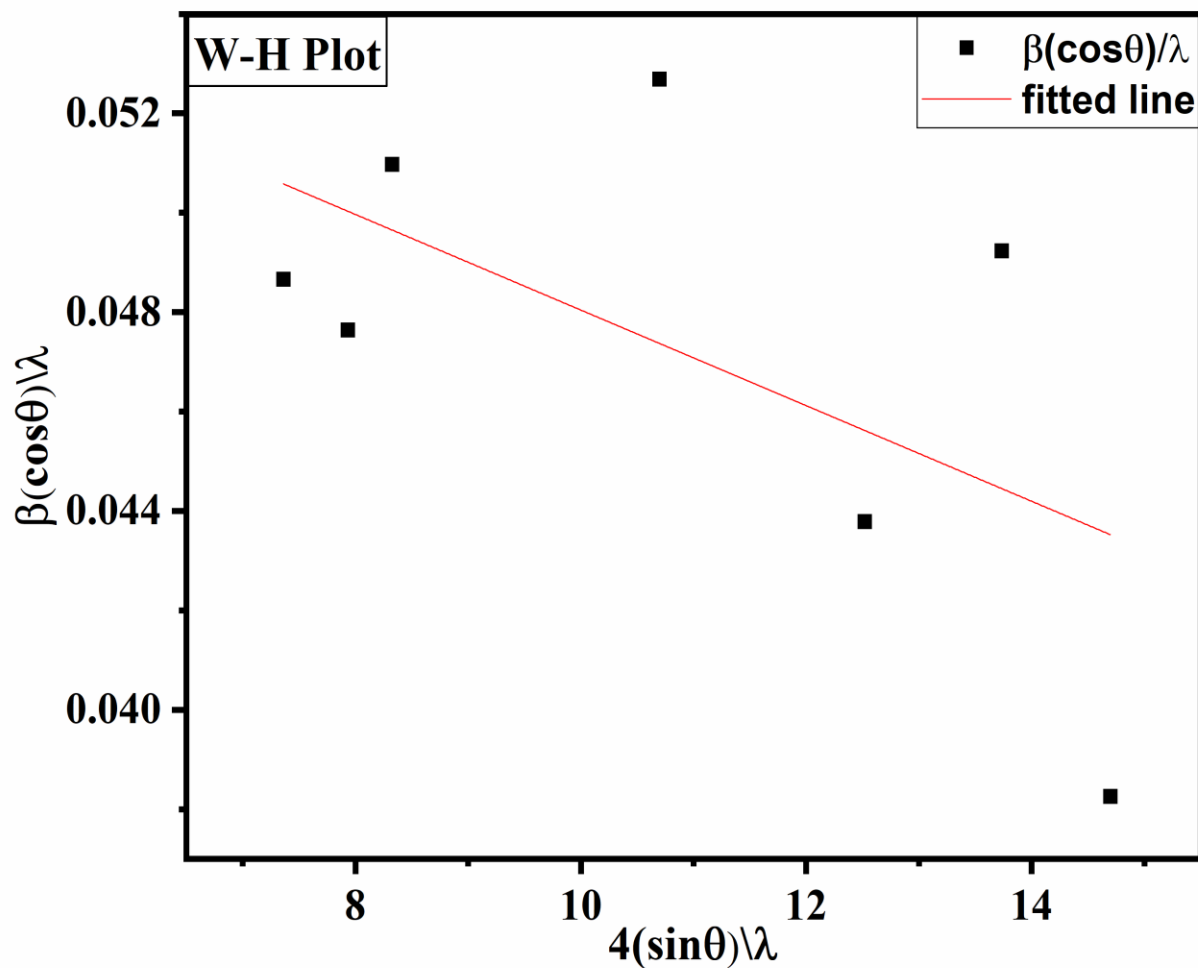


Figure 6: William-Hall (W-H) plots of pristine ZnO.

The crystallite size of the fabricated film calculated from the W-H plot was found consistent with that as calculated from Scherrer's method as tabulated in table 1.

Table no 1: Shows XRD analysis for miller indices, d-spacing and grain size of the deposited ZnO thin film.

S.N.	Miller Indices	Angle 2θ	Calculated d (Å)	JCPDS(36-1451) d (Å)	Crystallite Size D(nm)	
					Scherrer's Method	W-H plot
1.	(100)	32.95075	2.7172	2.8142	19.31788	Average 20.0678 17.3445
2.	(002)	35.60633	2.5204	2.6033	19.73324	
3.	(101)	37.42934	2.4018	2.4759	18.44347	
4.	(102)	48.69692	1.8692	1.9111	17.84351	
5.	(110)	57.69607	1.5972	1.6247	21.46739	
6.	(103)	63.92009	1.4559	1.4771	19.09518	
7.	(200)	69.00289	1.3605	1.4072	24.57326	

Scanning Electron Microscope (SEM) and EDX analysis:

The surface morphology of ZnO thin films were performed using Scanning Electron Microscope at Research Centre for Eco-Environment Sciences, Chinese Academy of Sciences, Beijing, China.

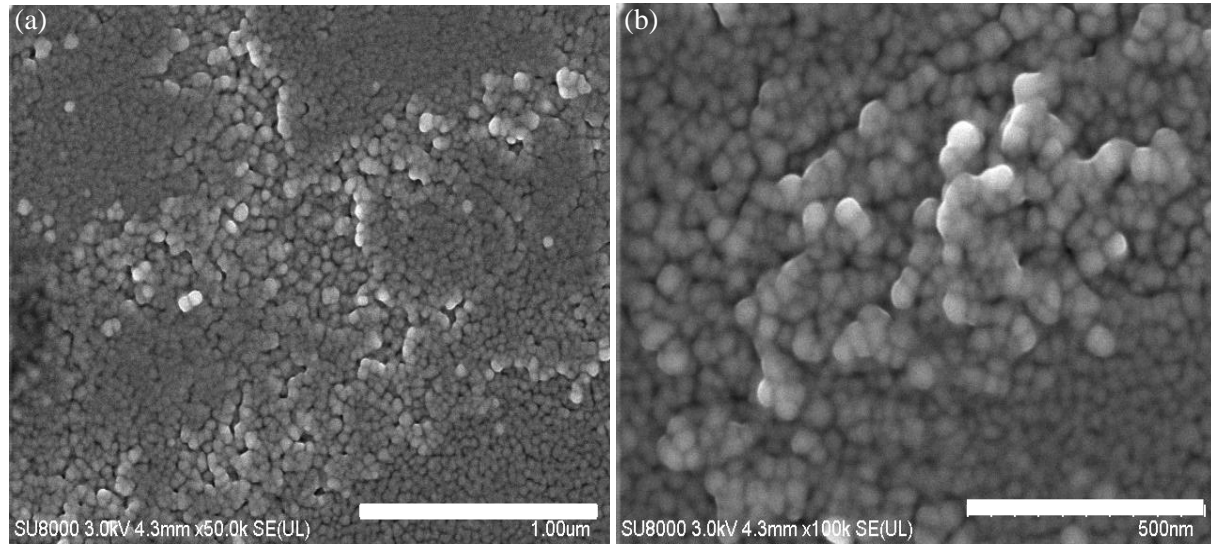


Figure 7: SEM images of ZnO thin film with scale (a) 1 μ m and (b) 500nm

Figure 7(a) and 7(b), shows the SEM images of undoped ZnO with scale 1 μ m and 500nm and magnification of 50K and 100K respectively. The SEM image depicts grainy structure of film. The average grain size of ZnO was found to be around 25 nm which is quite corresponding to results obtained from XRD analysis.

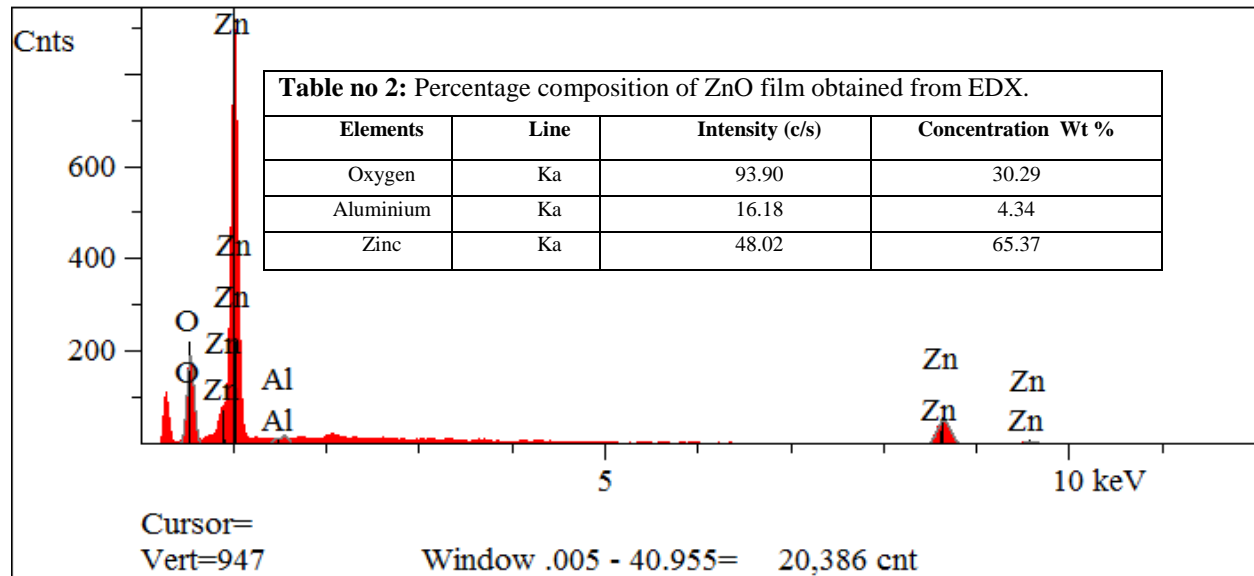


Figure 8: Energy Dispersive X-ray image of Pristine ZnO film.

Figure 8 shows the EDX spectra which assure that the film is of Zinc oxide. Very small peak of Aluminium is detected which may be due to Aluminium silicate (glass) substrate. The EDX spectrum of ZnO sample as figured in table 2 shows the high content i.e. 65.37 wt. % of Zinc, 32.29 wt. % of Oxygen and 4.34 wt. % of Aluminium which is almost negligible compared to oxygen and Zinc.

Circuit Analysis:

The circuit designed is the novel concept in sensing gas. Since the resistance of the film is influenced by material used for depositing thin film, the number of coating done, doping in film and aging of the film, the values of the resistors used in the circuit must be different for different value of film resistance at the ordinary condition. These values of the components must be appropriate to determine or sense the selected reducing gas. Here we present some particular values of these components and the critical point value of the film resistance (value of film resistance beyond which the output voltage of the circuit changes its polarity or the LEDs switch) for the particular configuration of the circuit. We analyzed the circuit fixing the feedback resistance and the ratio ($R_1: R_2$) and manually changing the value of film resistance unless we obtained critical value.

The film resistance of quite higher value than the critical value should be used for better sensing. Considering this, best range of the film was estimated and their corresponding sensitivity was calculated using the relation:

$$S = \frac{R_x - R_g}{R_x} \quad (\text{Eq. 4})$$

Where, S is sensitivity, R_x is film resistance before exposure to gas and R_g is the value resistance of film after exposure to gas.

Table no 3: Shows the values of Components to be used in accordance to film resistances and selected gas.

S.N.	Feedback Resistance R_f (K Ω)	Ratio ($R_1: R_2$)	Critical Point Value (K Ω)	Best Range of Film Resistance R_x	Minimum Sensitivity S (%)
1.	560	1:3	1679	(2-1.7) M Ω	(15-1.24)
	560	1:10	5999	(10-6) M Ω	(40-0.02)
	560	1:100	55899	(200-56) M Ω	(72-0.18)
2.	470	1:3	1410	(2-1.5) M Ω	(30-5)
	470	1:10	4759	(15-5) M Ω	(67-4.82)
	470	1:100	46899	(200-47) M Ω	(77-0.22)
3.	100	1:3	298.99	(400-300) K Ω	(25-0.34)
	100	1:10	999.79	(2-1) M Ω	(50-0.021)
	100	1:100	9982.56	(40-10) M Ω	(75-0.174)
4.	10	1:3	44.98	(80-45) K Ω	(44-0.04)
	10	1:10	99.98	(300-100) K Ω	(67-0.02)
	10	1:100	997.92	(3-1) M Ω	(67-0.02)
5.	1	1:3	2.999	(5-3) K Ω	(40-0.03)
	1	1:10	9.998	(30-10) K Ω	(67-0.02)
	1	1:100	99.82	(300-100) K Ω	(67-0.18)

Table no 3 represents the theoretical values for the circuital components for sensing the selected gas to approximate the appropriate value of feedback resistor, the ratio of R_1 and R_2 to be used in the circuit for sensing particular gas within a limited range of sensitivity. Further the tables, eases to choose the sensor components accordance to resistance of fabricated film. We need to select the sensitivity within which we are willing to work with. This helps finding the critical value using relation (4) and helps to approximate the feedback resistance and ratio $R_1:R_2$. Clearly, ratio of feedback resistance and critical value seems roughly equal to ratio $R_1:R_2$.

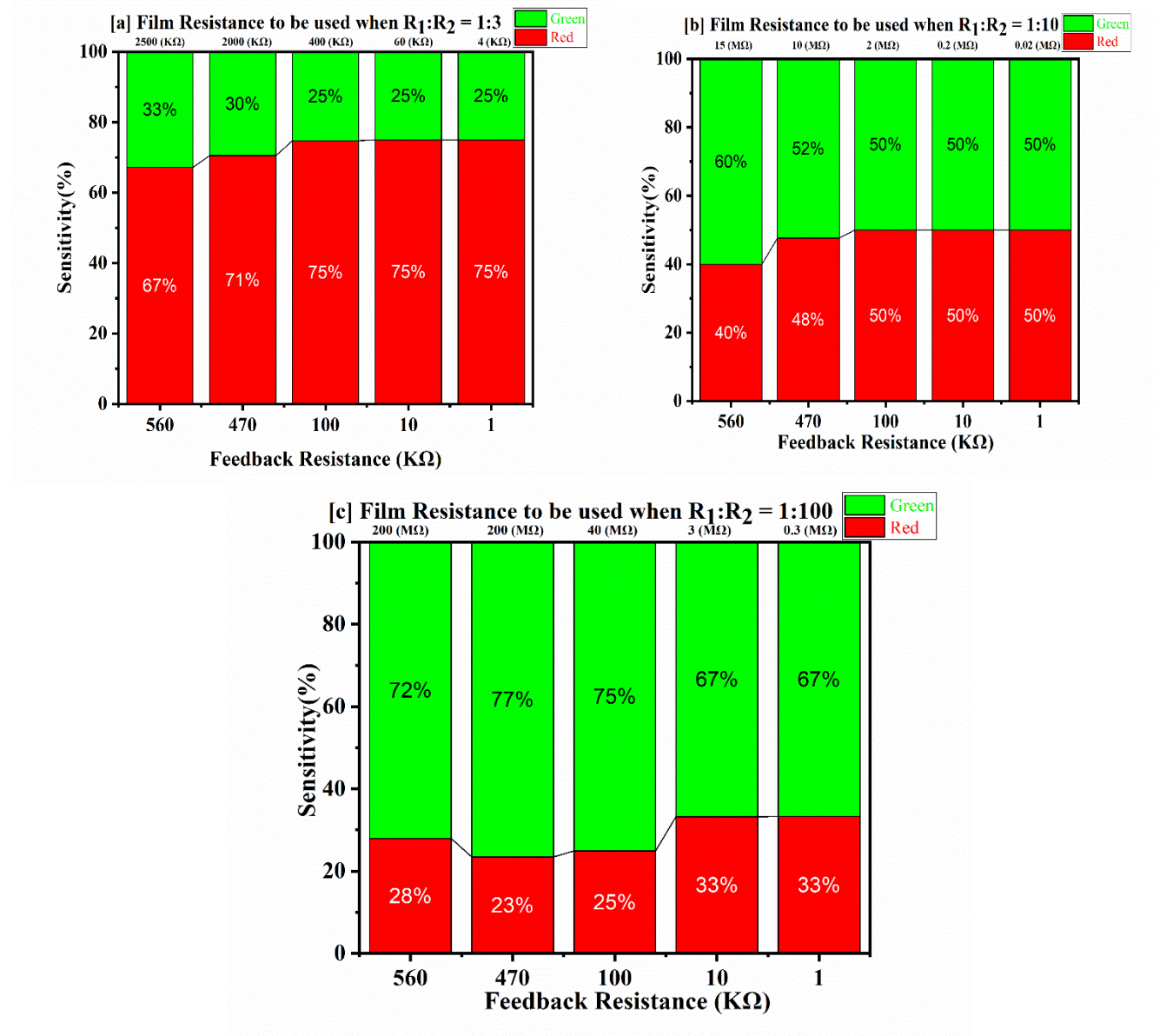


Figure 9: Sensitivity Stacked Chart for different ratio of R_1 and R_2 (a) 1:3, (b) 1:10 and (c) 1:100 and different values of Film and Feedback Resistances.

In the sensitivity stacked chart, figure 9a, 9b and 9c, for different ratio $R_1:R_2$ and different feedback resistance above, film resistance from which sensitivity is measured, is mentioned at the top of it. If we use the film of above mentioned resistance as sensor, and corresponding values of feedback resistance and ratio $R_1:R_2$, the sensitivity of the film on exposure to gas must be as indicated on green block so as to sense it. In other words, the exposure to gas

should reduce the film resistance by indicated values to detect the gas. These suggest that for higher film resistance, we should use higher value of feedback resistor or large $R_1:R_2$ for more sensitive sensor and for film resistance with low resistance, comparably small values of the components can be used.

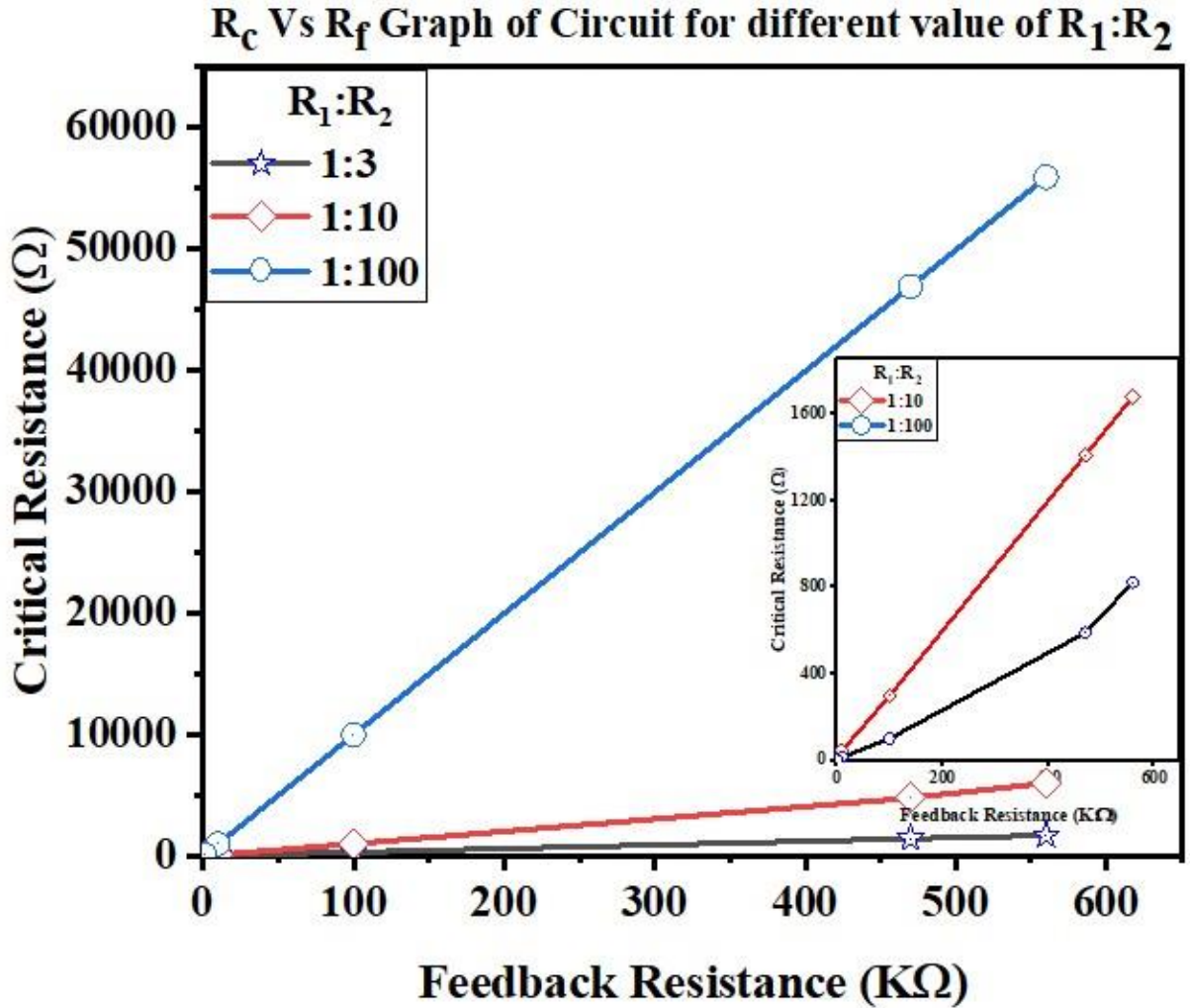


Figure 10: Critical vs feedback resistance graph at different ratio of R_1 and R_2 .

Figure 10 clearly depicts that critical point value or the critical resistance of the film is linearly dependent on the feedback resistance used in the circuit for same $R_1:R_2$. The critical resistance is such value of the film above which the circuit glows Green and below which results glowing Red. Also, it suggests that increment in the ratio $R_1:R_2$ yields higher value of critical resistance which will be very efficient for using highly resistive film as a sensor. Lower value of $R_1:R_2$ gives lower value of critical resistance which will be more effective if used with less resistive film. Furthermore, highly resistive film can be used as sensor along with lower value of $R_1:R_2$ if the target gas highly reduces the film below critical value. The mechanism is same for feedback resistor. Thus, appropriate value of $R_1:R_2$ and feedback resistor can let us sense reducing gas of any concentration.

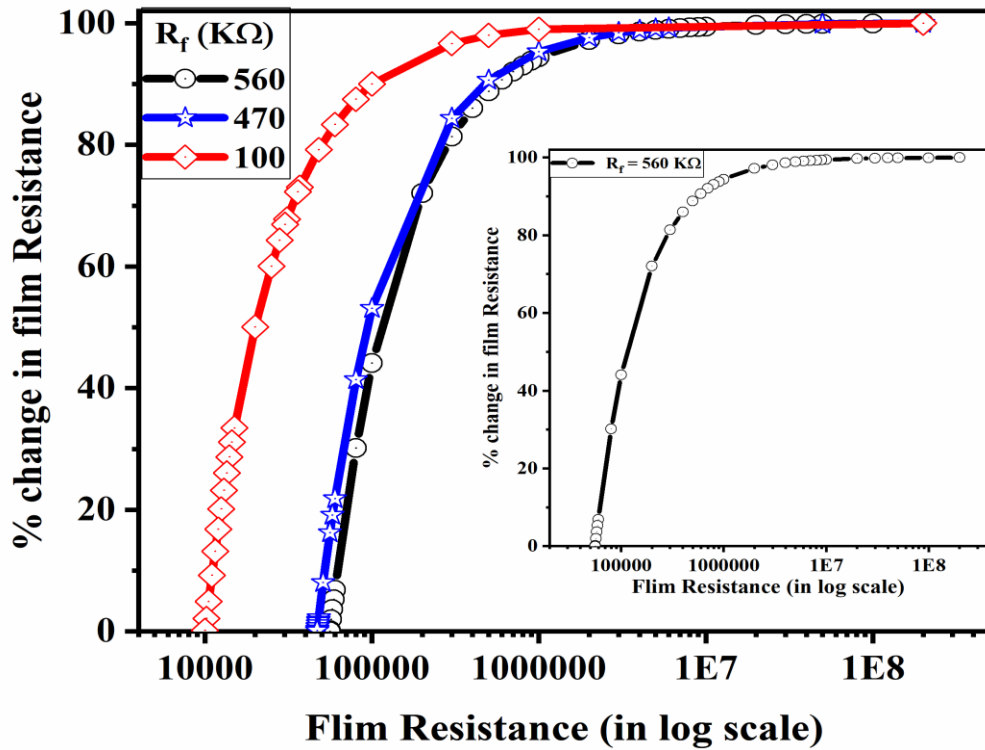


Figure 11: Least percentage change of Film Resistance required for sensing vs Film resistance graph for different value of R_f .

Figure 11 is the plot of film resistance (in log scale) vs least percentage change required for sensing the target gas at different value of feedback resistance for $R_1:R_2$ equals 1:100. The graph clearly shows that highly resistive film needs more than 90% change in their film resistance for sensing (RED glow in circuit) in above mentioned configuration. But Film resistance closer to the critical value of resistance can sense well within less percentage change in its former value. This circuit best suits for sensing even if the target gas increases the film resistance. But selecting appropriate and accurate $R_1:R_2$, feedback resistor and remaining circuital components is most for excellence performance.

Thus, analyzing Figure 10 and Figure 11, we can conclude that sensitivity of the circuit is dependent on the value of critical resistance of the film but not on the film resistance. This is the most fantabulous characteristics of the circuit which overcomes the dependency of the available ordinary sensors on film resistance. Furthermore, the critical value of the film is controllable. It depends upon the components used in the circuit. The film resistance may vary from few $K\Omega$ to hundreds of $M\Omega$ and no chemical synthesis yields film of desired resistance with accuracy which has brought complexation in sensing with desired accuracy. Thus, the noble circuit designed is the ultimate way to eradicate this drawback of the ordinary sensor. Finally, designation of sensor can be summed up as:

- (i) Measuring film resistance after fabrication R_x).
- (ii) Choosing sensitivity (S).
- (iii) Calculating Critical Resistance using selected sensitivity and Film Resistance as:

$$R_c = R_x - \frac{S \times R_x}{100} \quad (\text{Eq. 5})$$

(iv) Choosing appropriate value of R_1 : R_2 , R_f and other circuit components and fabricating sensor.

Experimental Verification:

This was experimentally verified using alcohol (ethanol and methanol) vapors as reducing gas and ZnO as sensing material in the film. The value of the fabricated film resistance was more than 200 M Ω , ratio (R_1 : R_2) was 1: 3, the value of feedback resistance was 560 K Ω and two eight pins chips (UA741CN) were used as amplifiers. Two LEDs (one red and another green) were fixed as shown in the circuit. 9 Volt battery was used as a source for two amplifier chips and another 3 Volt battery was conned in series with R_1 and R_2 . The film was exposed to different concentrations of gas (alcohol vapors) and corresponding change was noted. The table 4 represents the experimental values.

Table no 4: Value of Input and Output Voltages of Circuit before and after exposure to alcohol vapors.

S.N.	Gas	Concentration (ppm)	Potential (V)			
			Before passing gas		After passing gas	
			Input	Output	Input	Output
1.	Ethanol	500	0.35	-4.15	6.27	2.56
		250	0.36	-4.15	5.11	2.28
		50	0.35	-4.14	4.12	2.13
2.	Methanol	500	0.36	-4.14	5.56	2.52
		250	0.34	-4.15	4.92	2.23
		50	0.36	-4.13	3.98	2.06

The table 4 clearly shows the switching of potential at output of circuit due to exposure of alcohol vapors. This confirms that the designed circuit senses alcohol vapor (reducing gas) using pristine zinc oxide thin film.

Response and Recovery:

Response and recovery time are another indispensable factor for determining whether or not a sensor is reliable. Here we have tabulated response and recovery time of our circuitual sensor after exposure to different concentration of ethanol and methanol vapors in table 5.

Table no 5: Response and Recovery time of ZnO thin-film varying with concentration and types of alcohol.

S.N.	Alcohol	Concentration (ppm)	Response Time (s)	Recovery Time (s)
1.	Ethanol	500	2	60
		250	4	28
		50	6	10
2.	Methanol	500	2	80
		250	5	35
		50	8	15

The circuit remains in either normal state/zone (glowing Green) or in detection zone (glowing Red). When the target gas is passed, sooner the film resistance decreases and reaches the critical resistance, the circuit changes its state from normal and when the gas passes by, film resistance starts increasing again. As soon as it exceeds R_c , it changes its state back to normal. The time for which the circuit remains in either state while responding to different concentrations of Ethanol and Methanol vapors is shown below in Figure 12 :

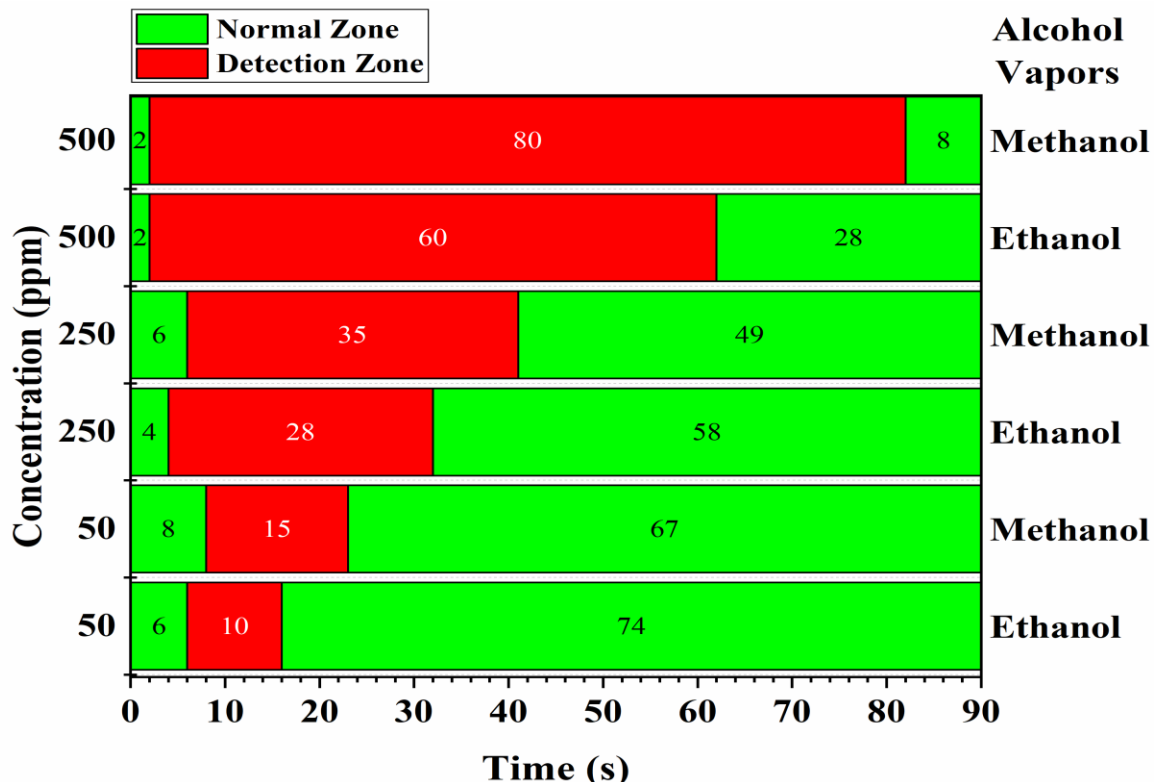


Figure 12: Time for which the circuit remains in either state in response to different concentration of alcohol vapors.

The figure 12 clearly depicts that higher the concentration, longer it stays in detection zone. Further, for same concentration, circuit responds faster to ethanol than methanol.

The vapors were passed simultaneously into the sensor setup and were free to escape at any time. The variation in film resistance in response to 50, 250 and 500 ppm of Ethanol and Methanol vapors were observed and are graphed as shown in Figure 13a and 13b. The graph reflects that the resistance of the film while responding reducing gases decreases rapidly for few seconds then slows down and reaches its minimum value. The minimum value is attained

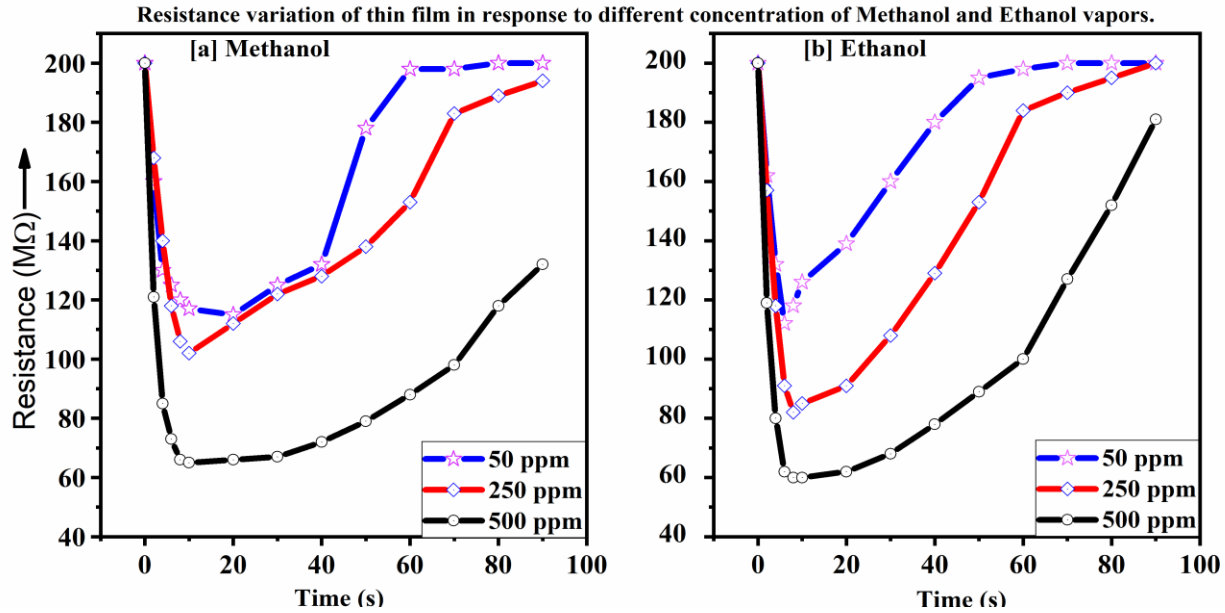


Figure 13: Variation of film resistance in response to various concentrations of Alcohol vapors.

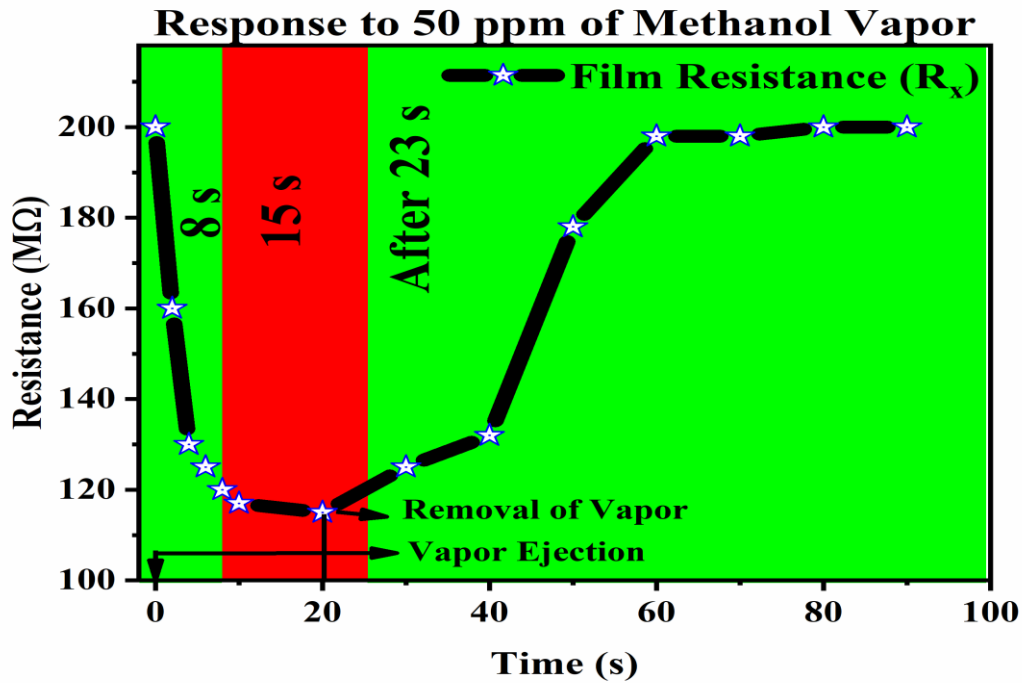


Figure 14: Film response to 50 ppm of Methanol Vapors.

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4 when the target gases replace maximum number of reduced oxygen molecules in the grain boundary of film. As
5 soon as the impact of the gas diminishes, the oxygen molecules in reduced form starts gathering at the grain
6 boundary region and the film resistance starts increasing again. Its obvious that lower the concentration, less is the
7 impact on film resistance.
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10 Clearly, the experimental result shows that the film is sustainable and is very sensitive to reducing gases. The
11 longevity of recovery time as observed in figure 14 may be due to poor ventilation for gas outlet in our experimental
12 setup.
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20 **IV. Conclusions**

21 The innovative circuit proposed for gas sensing utilizes a zinc oxide thin film to detect reducing gases effectively.
22 Once the thin film is fabricated, its resistance becomes known. By referring to Table 3, Figure 10, and Figure 11, we
23 can determine the optimal values for the feedback resistor and the ratio of R_1 to R_2 to be employed in the circuit for
24 sensing specific gases within a predefined sensitivity range.
25

26 Moreover, the electrical components utilized are readily available in compact sizes on the market. This enables us to
27 create a portable, miniaturized sensing device or sensor at a low cost while consuming minimal energy, all thanks to
28 the implementation of the zinc oxide thin film. Additionally, the circuit lends itself to straightforward breathalyzer
29 testing applications.
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