Ethanol Sensing application of Zinc Oxide-Tetrapod (ZnO-T) nanomaterials

A DISSERTATION

Submitted in partial fulfillment of the

Requirements for the award of the degree

Of

MASTERS OF TECHNOLOGY

In

SOLID STATE ELECTRONICS MATERIALS

By

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Roorkee

Candidates Declaration

I hereby declare that the work, which is being presented in the dissertation report entitled "Ethanol sensing application of Zinc Oxide- Tetrapod (ZnO-T) nanomaterials" in partial fulfillment of the requirements of the degree Masters of Technology with specialization in Solid state Electronics materials, submitted in Physics Department, Indian Institute of Technology Roorkee is an authentic record of my own work carried out during the period from July 2018 to June 2019 under the supervision of Dr. Soumitra Satapathi, Department of Physics, Indian Institute of Technology Roorkee, India.

The matter embodied in this report work has not been submitted for the award of any other degree.

Date

Place Shailey Singh

Certificate

This is to certify that the work related to dissertation entitled "Ethanol sensing application of Zinc Oxide – Tetrapod (ZnO-T) nanomaterials" carried out by Shailey Singh under the supervision of Dr. Soumitra Satapathi for the partial fulfillment of "Master of Technology" with specialization in "Solid State Electronics Materials.

The matter embodied in this report work has not been submitted for the award of any other degree.

Dr. Soumitra Satapathi

Acknowledgement

I would first like to express my sincere gratitude to my advisor Dr. Soumitra Satapathi Department of Physics, Indian Institute of Technology Roorkee. The door to Dr. Satapathi’s office was always open whenever I ran into a trouble spot or had a question about my research or writing. He consistently allowed this paper to be my own work but steered me in the right the direction whenever he thought I needed it.

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Finally, I must express my very profound gratitude to my family and friends for providing me with unfailing support and continuous encouragement throughout my dissertation period of study and through the process of researching and writing this thesis. This accomplishment would not have been possible without them. Thank you.

Author

Shailey Singh

Abstract

ZnO is an important n type semiconductor sensing material. It has been demonstrated that ZnO nanorods and nanowires exhibit many unique properties associated with their shape anisotropy and high thermal and chemical stability.

In this dissertation ZnO-T films were characterized and their role in ethanol sensing application is discussed and investigated. Films are examined electrically using the Four-probe setup and I-V conductivity measurement is carried out. Inter-digitized patterns were utilized for better electrical property analysis of the structure. ZnO-T structure and optical properties were observed by X-Ray Diffraction (XRD), Field Emission Scanning Electron Microscopy (FE-SEM) and Optical Microscopy.

Gas sensing results shows that there is a change in resistance due to current passing through the material in a microamps range. It is also observed that the film shows change in resistance when exposed to sunlight showing the behavior that of a photodiode.

Present work paves the way for the development of a novel low-cost gas sensor for practical application.

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CHAPTER 1 LITERATURE REVIEW

1.1 *Introduction* : *Why ethanol sensing?*

Ethyl alcohol, with the chemical formula C2H5OH is popularly known as ethanol. With the growing use of ethanol in our day to day life, its detection becomes a vital need of the hour. This work is basically about sensing ethanol content by best possible means due to its widespread applications. Ethanol is liquid at room temperature with a strong and burning odor. This colorless, volatile liquid burns with a white bright flame.
Some of its applications are listed below-

Personal Care-

Many of the personal care, cosmetics and beauty care products has Ethanol as a common ingredient. It is used to clean skin just like an astringent. It is one of the ingredients in lotions as a preservative. Moreover, it keeps the constituents of lotion separate and as an adherent in hairsprays, it helps the spray adhere to hair.

Ethanol has germ killing properties so it is used in killing microorganisms like bacteria, fungi and viruses. Many hand sanitizers use it for the same reason.

Household Products-

Ethanol is used in paints, lacquers and varnish. It is also a key ingredient in household cleaning products. It can be considered as an effective solvent as it exhibits good solubility with several organic solvents and is even fairly souluble in water.

Food Additives-

Enhancement of flavor food extract and even distribution of food coloring are also some of the utilities of ethanol. It is a popular food additive.

For example, vanilla beans which when processed and cured in a mixture of ethanol and water results in a common food flavouring called vanilla extract. Its name “extract” is approved by the Food and Drug Administration (FDA),United States only because of the fact that it has an alcohol or ethanol base. It is even approved as a safe edible alcohol. (provided consumed in controlled quantity).

Fuel-

It is even used as a fuel. It reacts with oxygen in air giving out carbon dioxide and water as the byproducts. Chemical reaction shown below-

$$CH_3CH_2OH + 3O_2 \rightarrow 2CO_2 + 3H_2O$$

It can even be used in combination with gasoline (petrol) for the same purpose. A mixture containing petrol and 10-20% ethanol is known as gasohol. Ethanol also has an application in reducing air pollution. 10 percent ethanol is used with 90 percent gasoline resulting in a mixture called E10. It oxygenates the fuel thereby reducing air pollution.

However, these many utilities of ethanol don’t make it a safe material. It has several hazards as well.

Safety Information

Ethanol is adviced to keep away from open flames as it is highly flammable. Inhalation of ethanol can cause certain health hazards like coughing or headaches. Ethanol is an important ingredient in alcoholic drinks, resulting in intoxication. A “denaturant,” (such as a bitter flavouring) is added in alcoholic drinks. It is done basically to discourage the consumption of pure ethanol. Denaturants does not alter the other properties of the substance, it just makes alcohol unsuitable for human consumption.

A vast range of applications of ethyl alcohol or ethanol makes is a matter of interest for the detection purposes.

1.1 Zinc Oxide (ZnO) as a sensing material

When it comes to sensing applications, semiconductor oxide-based sensors are largely preferred over other sensors as these are portable, affordable or inexpensive, have high response, show **good reversibility** etc.

These properties make them a popular choice for detection of toxic, inflammable and foul-smelling gases. They are even looked forward for their use in detection of organic compounds thereby replacing the traditional chemical analysis done for the same.

Semiconductor oxides have wide range of applications in technology such as photocatalysis, piezoelectricity, optoelectronics, photovoltaic conversion and gas sensing by the virtue of its wide band-gap [7].

In recent years, extensive research has been carried out in semiconductor oxides such as SnO2, Fe2O3, CuO, TiO2, Ga2O3 and ZnO. Among them, ZnO has been looked upon as one of the most promising and reliable gas sensing materials [7].

Zinc Oxide (ZnO) has high electrochemical stability, non-toxicity, suitability to doping, and low-cost availability. ZnO is a distinguished candidate for electronic and photonic applications because of the combination of direct wide band gap (3.35 eV), large exciton binding energy (60 meV) hence responsible for efficient UV emission (~380 nm). It exhibits piezoelectric properties and excellent chemical and thermal stability as well.

In the past decades, ZnO has shown huge applications in various forms of ultraviolet (UV) and blue light-emitting devices, solar cells, piezoelectric devices, acousto-optic devices, varistors, transparent thin film transistors and chemical sensors, etc. It is transparent in the visible region. ZnO also has an ability to operate in harsh environments. It is radiation resilient. It is chemically more stable and capable of operation at much higher temperatures than Ge or Si.

Research has been encouraged in many applications due to the properties of ZnO, such as light emitting or laser diodes, transparent conducting oxides (TCO), photocatalysis, piezoelectric applications etc. It possesses a combination of attractive and unique optical, piezoelectrical, sensing and magnetic properties [6].

Over and above that, ZnO was pioneering material in gas sensing which would be presented in this work further. ZnO tetrapod is used instead of its bulk form for a specific reason which is explained in detail below [6].

Crystal Structure of ZnO

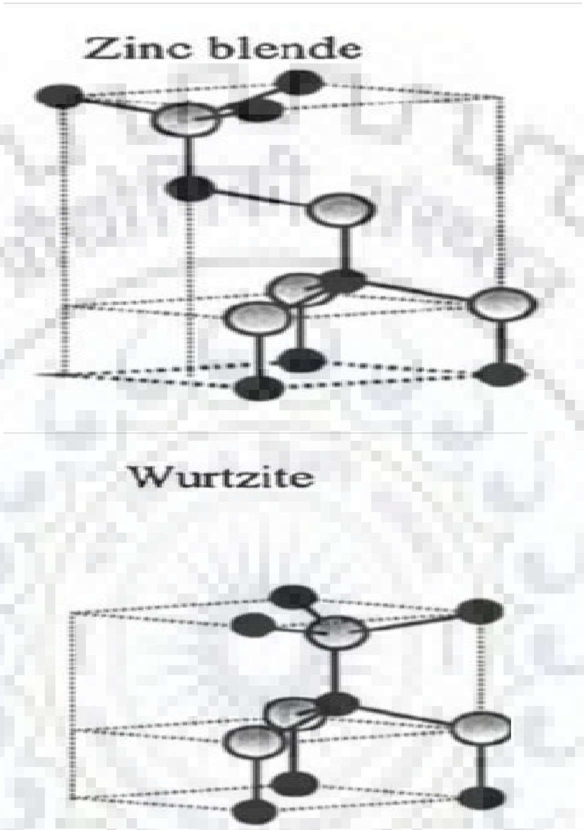


Fig. 1

ZnO exhibits polytypism, that means it can exist both in the hexagonal wurtzite and cubic zinc blende structure.

Wurtzite and zinc blende structures are depicted in the figure above. Wurtzite structure is the structure in which every zinc atom is coordinated tetrahedrally with four oxygen atoms. It is more stable structure as compared to the other, considered thermodynamically at ambient conditions [4].

The structure of ZnO can be simply described as several alternating planes composed of tetrahedrally coordinated O2 and Zn2+ ions, stacked alternatively along the c-axis. The wurtzite structure is most stable at ambient conditions and thus most common. If we can grow ZnO on substrates which have cubic lattice structure then even the The zincblende form can be stabilized.

T-ZnO (ZnO at nano Scale)

It has been demonstrated that ZnO nanorods and nanowires exhibit many unique properties associated with their shape anisotropy and high thermal and chemical stability. Due to the high aspect ratio of nanorod/nanowire, the active volume that contributes to the dark current is much smaller than that of a conventional detector. Hence increasing the sensitivity [1].

ZnO has been a popular choice of interest of researchers. Due to which certain hidden aspects of ZnO has been discovered. With the advent of modern nanotechnologies, a large variety of nanostructures in form of nanoparticles, nanowires, nanobelts, nanorods or nano- tetrapods have been synthesized. These morphologies ae ideal for gas sensing [6].

A significant finding is made as per the recent researches. The works claim superior performance of newly achieved two-dimensional nano- morphologies in comparison to traditional round-shaped three-dimensional nanoparticles. They claim that the size confinement in two dimensions, result in improved surface chemical characteristics, show better crystallinity and large surface to volume ratio [6].

CHAPTER 2 SYNTHESIS AND CHARACTERIZATION OF ZNO-T

2.1 *Synthesis of ZnO-T*

Recently, great emphasis is given on the growth and synthesis of tetrapods. This itself makes it obvious about their significance in various technological applications. Even though, their mass scale fabrication was a big technical challenge. This target has been successfully achieved by the recently introduced flame transport synthesis (FTS) approach by Yogesh K. Mishra in his work by simple flame transport Approach [3].

Some of the other methods of ZnO-T growth processes are given in the table below [2]-

METHODS	CONDITIONS	QUALITY
VAPOR-PHASE	Zn sublimation in air oxygen mixture, pressurized electric furnace	ZnO tetrapods with long arms(30–200mm); poor yield
WET CHEMISTRY	Growth in a chemical vessel (200–300 °C)	Tetrapod arms; broad size distribution; poor yield
HYDROTHERMAL	Aqueous solution ZnSO4 and NH3 in a reactor	Uniform tetrapods; multistep process; poor yield
FLAME TRANSPORT SYNTHESIS	Conversion of ZnO microparticles into tetrapods; sublimation and regrowth (Solid- vapor-solid process)	Tetrapods in large quantities, powder form; uniform narrow size distribution; highly crystalline; PVB process; yield ~25%; direct growth
VAPOR PHASE GROWTH	Zn evaporation; tube furnace (700 °C);	Arm (length up to 2 mm, dia 100 to 300 nm)
COMMBUSTION METHOD	Combustion of ZnO microparticles in reactor in air; continuous synthesis approach; multi step process	Uniform nano tetrapods; relatively broad distribution size; lower yield

2.2 Characterization

2.2.1 X-Ray Diffraction –

Small angle diffraction is opted for this sample property detection. X-Ray beams are allowed to pass through the sample. The atomic planes of the crystal cause the incident beam to interfere with one another as they leave the crystal. Thereby we get a diffraction pattern as a result.

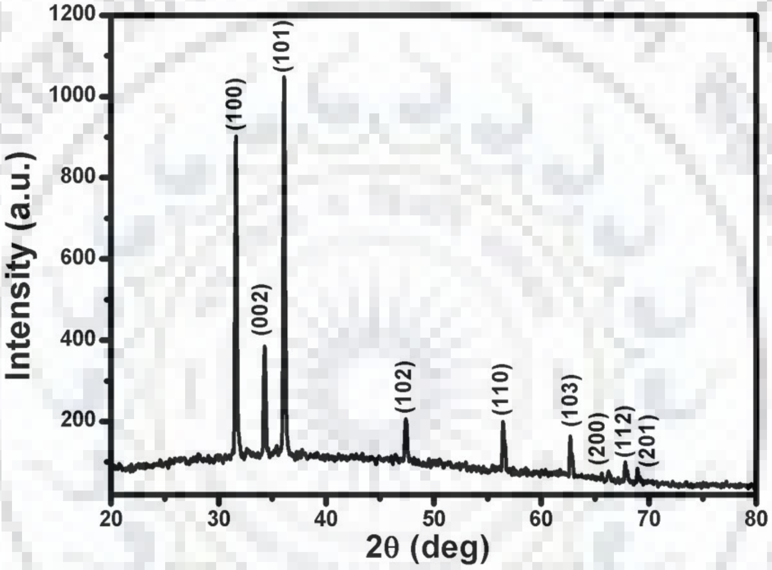


Fig 2. XRD Image of ZnO-T

All the diffraction peaks can be indexed to a Wurtzite structure with lattice constants of a=0.324nm and c=0.519nm while their intensity distributions are consistent with the standard card for the hexagonal ZnO crystal [5].

2.2.2 Field Emission Scanning Electron Microscope (FE-SEM)-

In FE-SEM setup, uses a focused beam of electrons is liberated to generate a scanned image or to analyze the sample under test. In this technique, electrons are made to fall on specimen by a field emission source. The sample under examination is exposed to these electrons. This is how we obtain a scanned image of the sample.

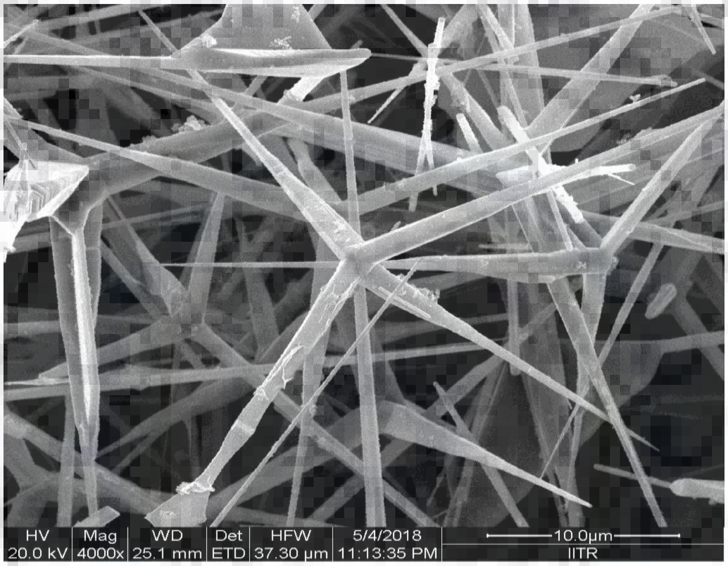
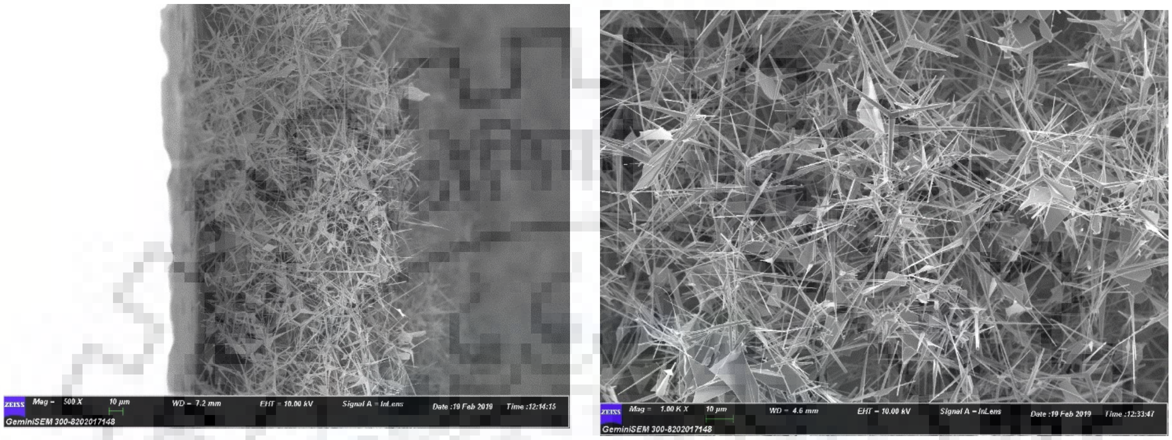


Fig 3. FE- SEM image of ZnO-T

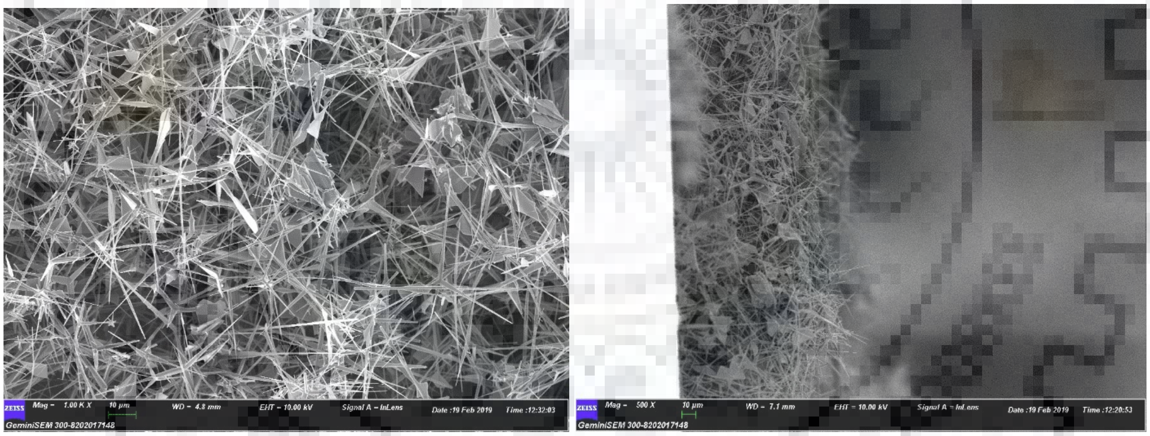
These show uniform tetrapods, a junction with four arms branching from the same center, and the angles between the arms are nearly similar to the spatial geometry of methane molecule.

FE-SEM images are also taken for different concentration as shown below-



(a) Cross section of 40mg film

(c) Front image of 40mg film



(b) Front image of 30mg film

(d) Cross section of 30mg film

Fig 4. ZnO-T dispersed in NMP solvent

2.2.3 Optical Microscope-

Optical microscope works by simple mechanism. When light is incident on the specimen at the bottom, either it travels straight through or reflects off the surface, penetrating through the lenses into the eyepiece. Microscopes that use light are called optical microscopes unlike the ones which use electrons for seeing instead of light. Those are known as electron microscopes.

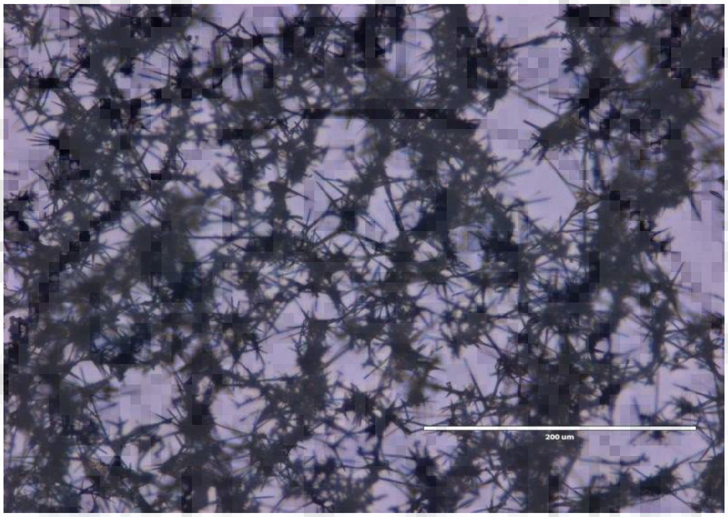


Fig 5. Optical Image of T- ZnO

Junctions in the tetrapod structures, are suggested to play a decisive role in the electrical characteristics of the ZnO tetrapod devices. Unlike the conventional nanowire-based gas sensors, such a sensor has an additional unique feature. Thus, the enhanced sensitivity is achieved by the virtue of the junction.

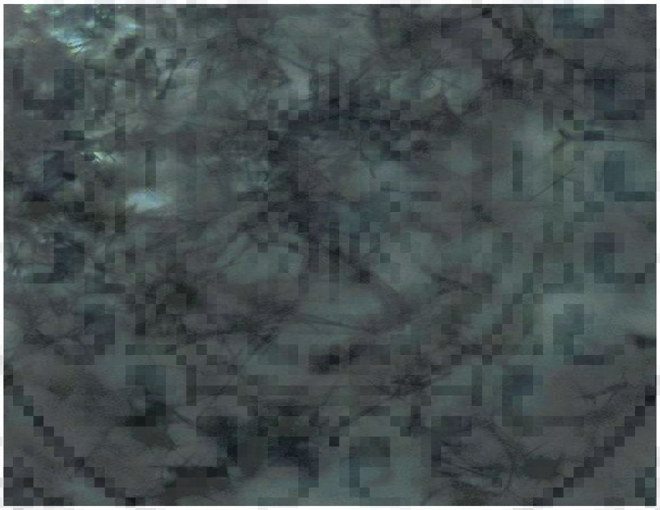
Considering the basic structure of ZnO, oxygen ions on the surface of the ZnO tetrapod can contribute largely on UV and gas sensitivity due to the absorption of O2 on the surface of ZnO. This relationship has been investigated by sensing UV light and O2 gas simultaneously. This effect indicates that e–h recombination rate in the ZnO nanorod legs is relatively slow, but this could be of some significance in further studies of photocatalytic activity.

The ZnO tetrapod-based sensor was also investigated in various environments, such as 100ppm H2, CO, *i*-butane, CH4, CO2, and SO2 at room temperature. It is reported that sensor is much more sensitive to H2, *i*-butane and CO, than to CH4, SO2, and CO2. It is also believed that, a novel multisensory structure can be developed by using ZnO tetrapod as a building unit in novel multiterminal devices.

Such sensors will be able to avoid “false response” or can be used for different sensing information.

Optical images taken for different concentrations-

(a)



(b)

Fig 6. (a) 30mg of ZnO-T in solvent (b)44 mg of ZnO-T in solvent

CHAPTER 3 ELECTRICAL SENSING BY ZNO-T

Several works are already reported showing the optical properties of ZnO-T in the field of sensors [5]. This work is about the electrical properties of the material which shows variation on exposure to the ethanol vapors.

Electrical sensing indicates the change in electrical properties of the material on exposure to the material to be detected. To be precise, the changes in the electrical resistance of the material is closely observed for the alcohol detection.

Generally, the sensors work on surface adsorption phenomena. The surface of the semiconductor metal oxide adsorbs the gas molecules in case a sensor is exposed to a reducing gas. Adsorption of a gas molecule on the surface reduces the potential barrier by injecting electrons to the conduction band, allowing the electron to flow easily and thus reducing the electrical resistance.

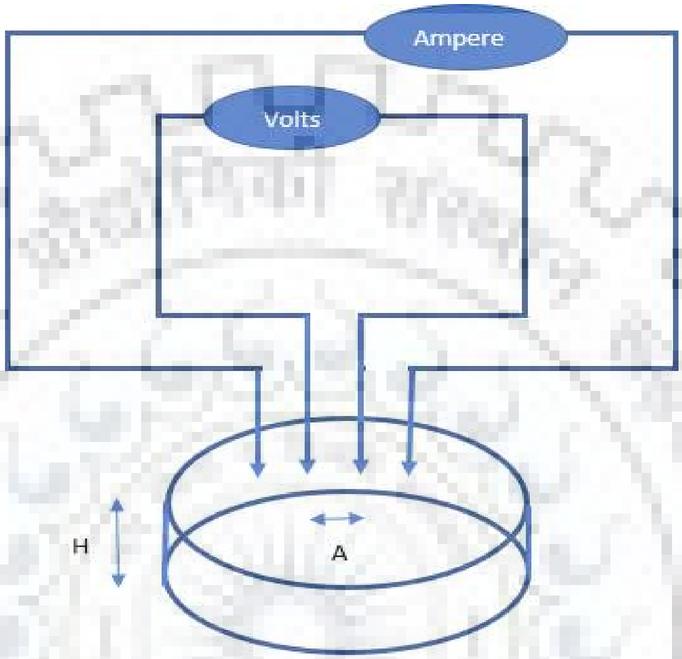
Talking about the electrical properties, then the ones of interest are mainly Conductance and resistance. By electrical sensing we mean having a close watch at any of these properties and changing the surrounding conditions. Exact functioning of the commercial devices for gas sensing application is also electrical sensing. It is discussed in further detail later in this chapter.

For this work, several methods are adopted for electrical sensing of ethanol vapors. They are listed as follows-

a) Four- Probe Method
b) I-V curve simulator
c) Gas sensor structure with ZnO-T as sensing layer

These methods are discussed in detail further one by one.

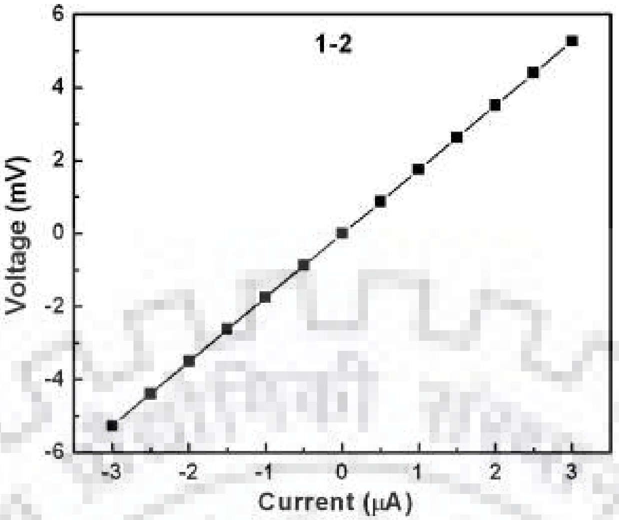
3.1 *Four - Probe setup -*



H – Thickness of the sample in centimeters
A - The distance between the probes in centimeters
Fig 7.

In this method, the specimen is kept on a metal base and the four metal contacts are touching the specimen. External two pins or contacts allow current to flow through the sample. Inner ones are utilized for voltage measurement. I-V curves can be plotted by the information obtained as a result. Slope gives the resistance.

Four - probe setup is used for the electrical analysis of the material. I-V curve in ideal case should be a straight line shown below [1] but due to some impurities measured curve is slightly deviated from ideality depicted in the later curves in chapter 4 [Results and Discussions].



ig. 4. *I–V* characteristics of the single ZnO tetrapod device through leg pair 1–2.

Fig 8.

Here, the I-V curve shows the straight line, slope of the curve gives the resistance of the material. With some calculations and known parameters, resistivity of the material can also be determined. Four-probe setup is actually used to determine sheet resistivity of the specimen. Here, for current work only the curve or the I-V characteristics are utilized.

Drawback of this method:

As the specimen used in this method is film dispersed on glass substrate. So, the outer electrodes which are responsible for the flow of current though the film may face some discontinuity. ZnO film being in its tetrapod form is difficult to be deposited as films offering a continuous path to current.

3.2 *I-V curve simulator –*

Sample used in this method is different from that used for the previous method. Discontinuity in the film is rectified using the interdigitated pattern as electrodes, it is made by etching the pattern on the Fr4 sheets as shown in figure.

Interdigitated electrodes

Tetrapod-ZnO structure is discontinuous when formed as a film which affects the additional increment in the resistance. For rectifying this, interdigitated pattern is incorporated. A stencil of desired pattern size is used. Fr4 sheets are cleaned and the design is heat printed on it or it can even be painted using the stencil.

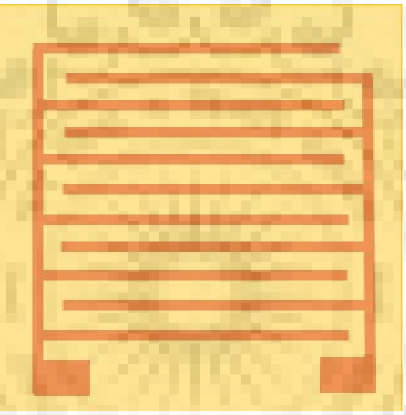


Fig 9. Cu pattern on Fr4 Sheet

Copper layer is etched away from the undesired parts with the help of etchant in the presence of sunlight. ZnO film is coated on this interdigitated pattern for further analysis.

Solar simulator is employed for the real time analysis of the film. Specimen containing the sensing material is kept under observation and ethanol vapors are liberated over the sample. Current flowing through the specimen is observed in real time. Also, the change in the I-V curves is observed before and post exposure to the ethanol vapors. Slope of these curves give the resistance or conductance variations.

I-V curve simulator is also used for detection of solar cell characteristics of the cell. P-N junction behavior of the cell is studied in forward and reverse conduction for photovoltaic applications.

3.3 *Conventional gas sensing device –*

Gas sensor structure

For checking the gas sensing properties of the material, ZnO/SnO2 is needed to be mounted on a structure as shown in the figure.

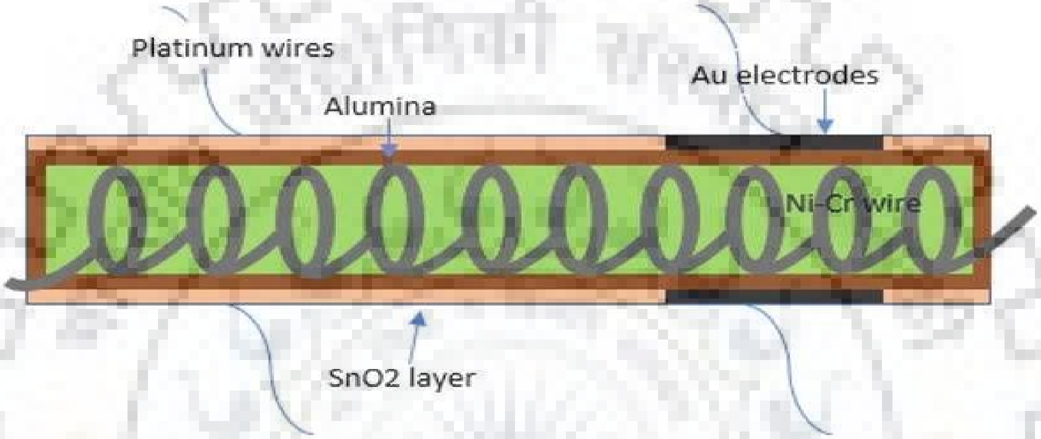


Fig 10.

An alumina tube is coated with the sensing layer of ZnO-T. Sensing material should be in aqueous form or paste form (a few drops of solvent and the sensing material). A Ni-Cr wire is made to pass through the tube. This creates the working temperature of the device. Au electrodes are deposited on the tube from where platinum wires are drawn out for the external circuit.

This paste after coating on the structure is made to dry under IR light, sintering at 873K for 1 h in a vertical furnace to provide good mechanical strength.

Working in commercial device

MQ3 gas sensing module is used as a reference to understand the functioning of the sensing device.

An alumina tube is used on which Au electrodes are present. Sensing layer of SnO2 is coated on it. A Ni-Cr wire is made to pass through the tube, this works as a heating element. Pt wires are drawn from the electrodes to the external circuit.

When the module is connected to the power supply the heating system makes the semiconducting layer as conducting. So the ethanol vapors come in contact to the electrode and converted into acetic acid. This increases the flow of current hence the vapors are detected.

CHAPTER 4 RESULTS AND DISCUSSION

4.1 *I-V Characteristics of the ZnO-T film by four Probe Method*

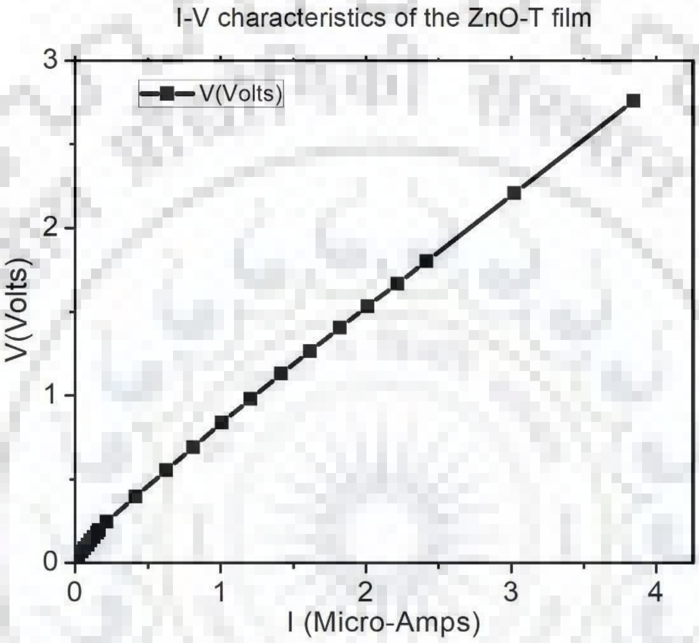


Fig 11.

(a) I-V characteristics in normal atmospheric conditions

Experimental Details –

ZnO-T in aqueous form is dispersed on a glass substrate and a film is formed. This film is kept under the four-probe setup for observation. Now, Current flowing through the specimen is allowed to vary gradually in steps and voltage corresponding to it is recorded at every step. I-V curve is plotted from the data obtained.

Analysis –

I-V curve obtained is a straight line similar to that reported in one of the previous works. [1] (also mentioned in section 3.1)

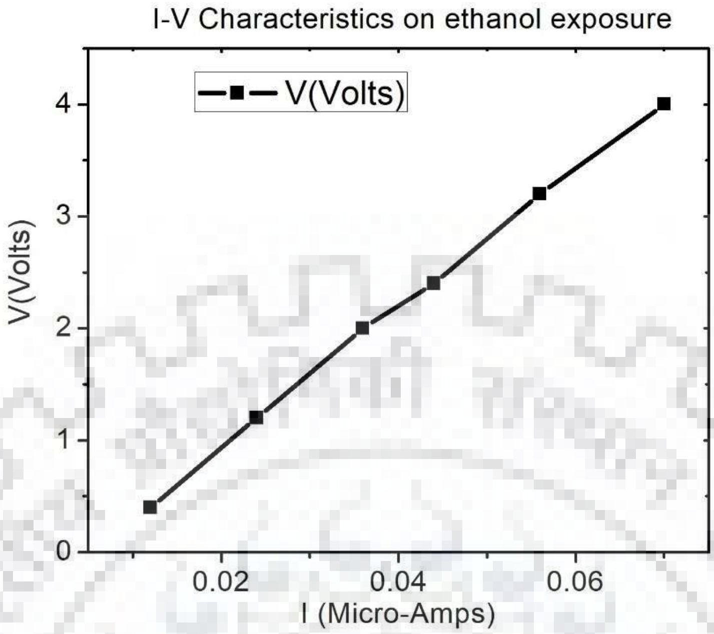


Fig 12.

(b) I-V characateristics after exposing the film to ethanol vapors

Experimental details-

Specimen preparation is same as that for the previous one. Just the surrounding conditions are changes that is ethanol vapors are liberated onto the film and then the Current voltage reading are recorded. I-V curve is obtained from the data recorded as a result for further analysis.

Analysis-

There is a shift in the slope of I-V curve clearly indicating the change in electrical properties of the material when exposed to ethanol vapors. This suggests that ZnO-T can be suiltaably used in ethanol gas sensing applications as it responds electrically to the exposure of ethanol vapors.

4.2 Periodic Observation on Exposure to ethanol

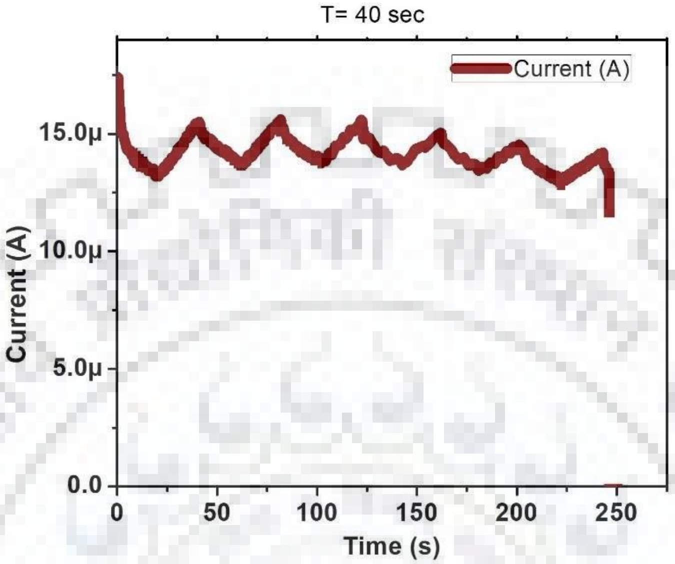


Fig 13.

(a) Time period – 40sec

Experimental Details- ZnO -T film is dispersed on interdigitated pattern so as to ensure the conducting path between two electrodes. This specimen is connected to the I-V simulator using the connecting wires and its properties are investigated in real time.

Analysis- Film is exposed to ethanol vapors for 20sec and removed for 20sec. As shown from the graph, current increases when exposed to ethanol and it decreases when kept away from it. Clearly indicating the decrease in resistance on detecting ethanol vapors.

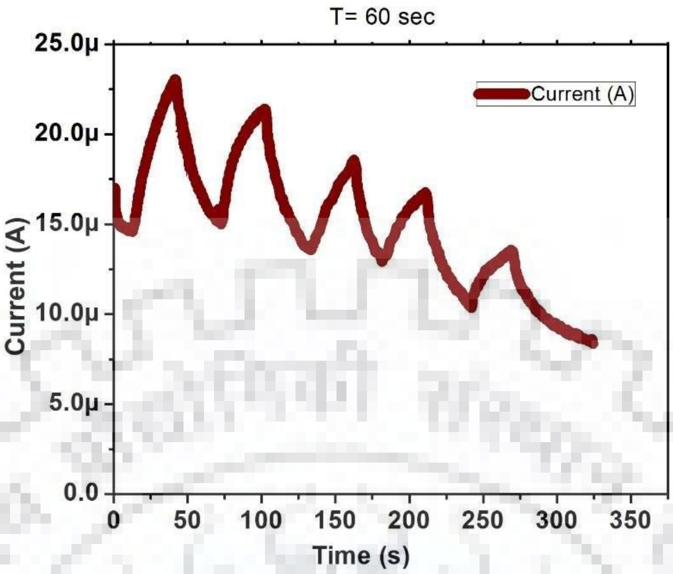


Fig 14.

(b) Time period – 60sec

Experimental Details-

ZnO -T film is dispersed on interdigitated pattern so as to ensure the conducting path between two electrodes. This specimen is connected to the I-V simulator using the connecting wires and its properties are investigated in real time.

Analysis-

Film is exposed to ethanol vapors for 30sec and removed for 30sec. As shown from the graph, current increases when exposed to ethanol and it decreases when kept away from it. Clearly indicating the decrease in resistance on detecting ethanol vapors.

Note: Decrease in peak in the cycles in succession is due to the decrease in the vapor pressure while observation.

4.3 Different Sample Observation on Exposure to ethanol

Experimental details-

Five different samples are prepared in the same manner as that described in the previous section [Section 4.1]. Each sample is kept under ethanol vapors for different time durations for having a better understanding of the electrical sensing process. Analysis of each result is written respectively.

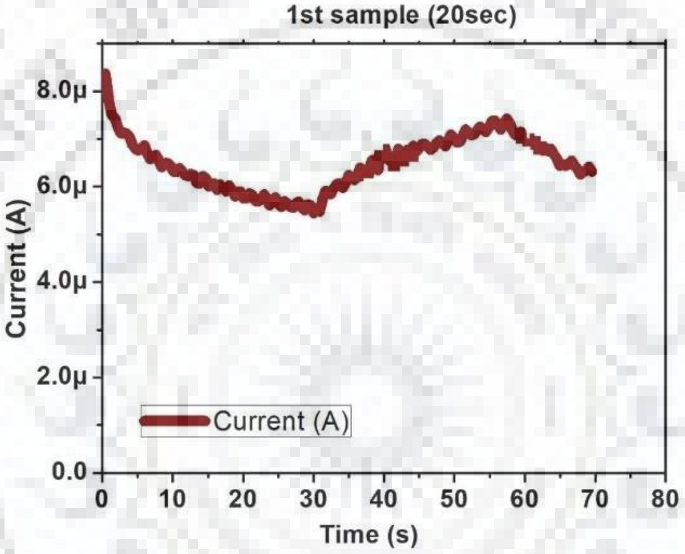


Fig 15.

(a) Sample 1- First sample is kept under ethanol surrounding for 20seconds and a current peak of 7 micro amps is recoreded.

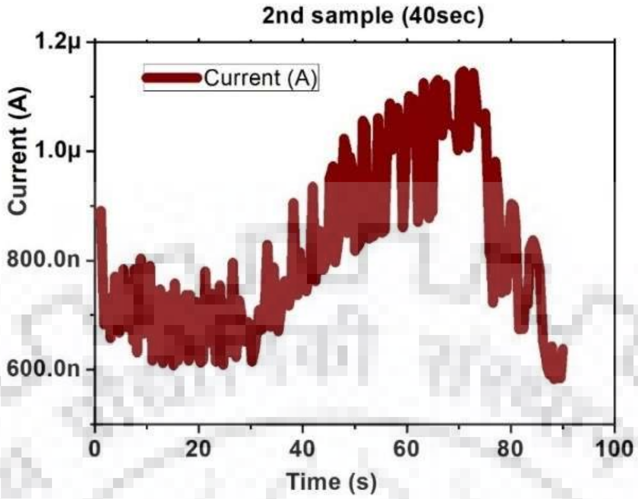


Fig 16.

(b) Sample 2- Second sample is kept under ethanol surrounding for 40seconds and a current peak of 1.18 micro amps is recoreded.

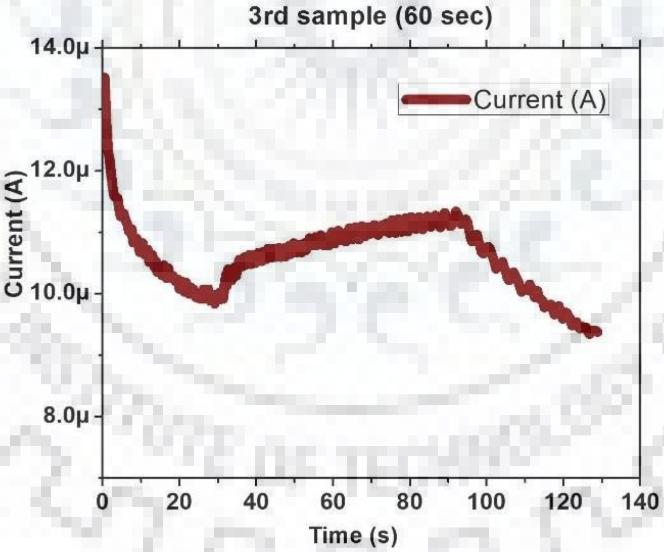


Fig 17.

(c) Sample 3 - Third sample is kept under ethanol surrounding for 60seconds and a current peak of 11 micro amps is recoreded.

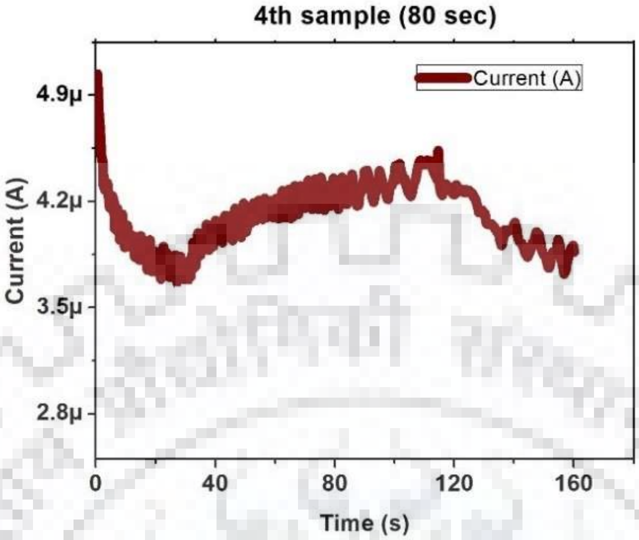


Fig 18.

(d) Sample 4- Fourth sample is kept under ethanol surrounding for 80seconds and a current peak of 4.6 micro amps is recoreded.

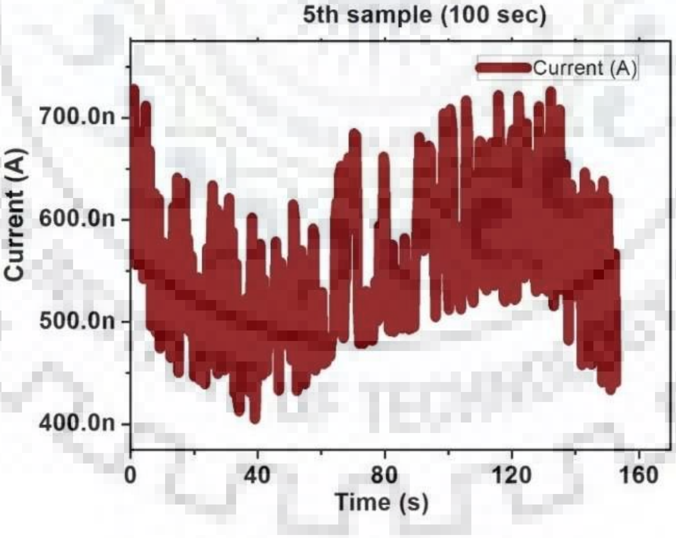


Fig 19.

(e) Sample 5- Fifth sample is kept under ethanol surrounding for 100seconds and a current peak of 750 nano amps is recoreded.

4.4 Effect of ethanol on multiple samples of ZnO-T

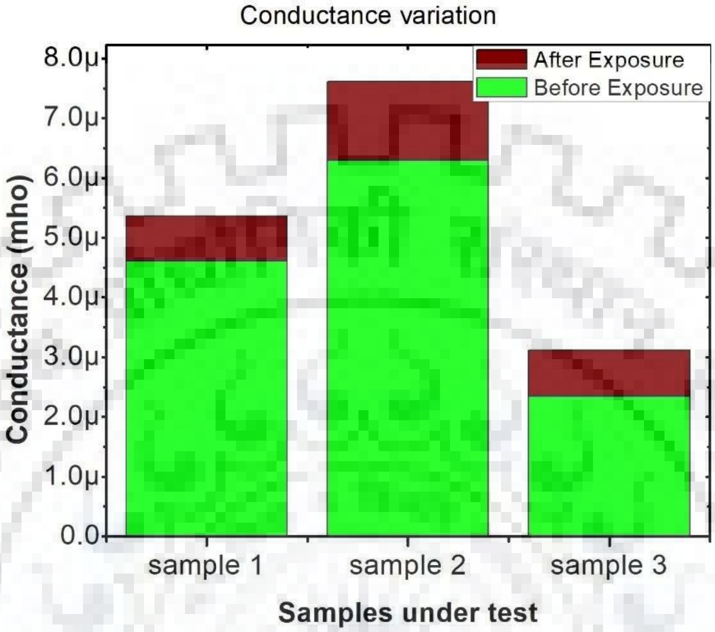


Fig 20.

Experimental details-

Sample prepared for I-V simulator is kept under observation. I-V curve are obtained first in the absence of ethanol and then vapors are liberated on the specimen. Changed I-V curve is also obtained. Change in the slopes are calculated and plotted as shown.

Analysis-

Three samples are taken under observation. There is significant increment in conductance in all the three samples after their exposure to ethanol vapors.

4.5 *Effect of ethanol with multiple sensing conditions*

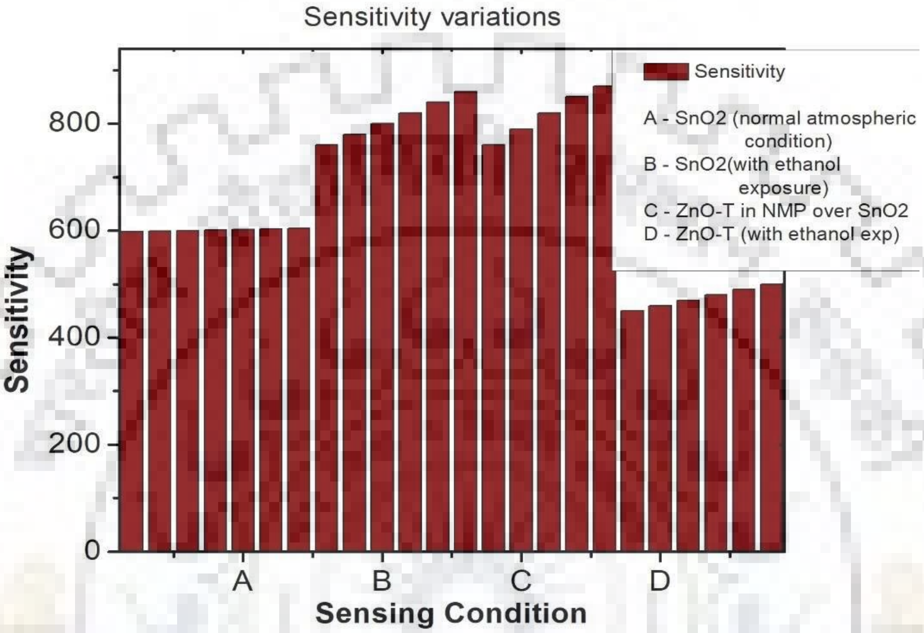


Fig 21.

Experimental details –

Gas sensor structure is tested with SnO2 and ZnO-T as sensing layers. On observing under different conditions for comparative study, sensitivity changes are recorded and plotted on the graph as shown above.

Analysis –

SnO2 as used in commercial device shows clear change in abalog value from 580 to 850 around in presence of ethanol. ZnO-T shows significant increment in sensitivity as the analog value shoots to 450 and beyond though previously it was around 100-200. Indicating its responsive behavior towards ethanol, it becomes a promising material for sensing applications.

Detailed description of each sensing condition-

(a) Default Composition (SnO2 with normal atmospheric condition)

This is the case of commercial devices available for gas sensing application. When used in absence of ethanol, it shows an analog value of 400 on the serial monitor.

(b) Default Composition (SnO2 with ethanol vapor condition)

Same composition that is SnO2 as sensing layer with ethanol vapors shows the increased analog value to 860 and above.

(c) ZnO-T layer Over SnO2

Fig 22.

ZnO-T aqueous solution is coated over the layer of SnO2 one. This results in the shooting up of analog value to 870 and above as the sensing layer is still SnO2 and it considered ZnO-T as an external agent (or the material to be detected).

(d) ZnO-T as the sensing layer

Fig 23.

SnO2 layer is removed and replaced by ZnO-T layer. On detection of ethyl alcohol vapors the analog value on the serial monitor shoots to 500 and above.

Customizing the complete structure

Other than this, we tried to check the response of other materials whether or not they show better sensitivity than the conventional gas sensing structure. The structure is customized as relacing Platinum wires with that of copper ones and sensing layer as ZnO-T dissolved in N-Methyl 2-Pyrrolidone solvent.

Fig 24.

4.6 *ZnO-T films responding to light*

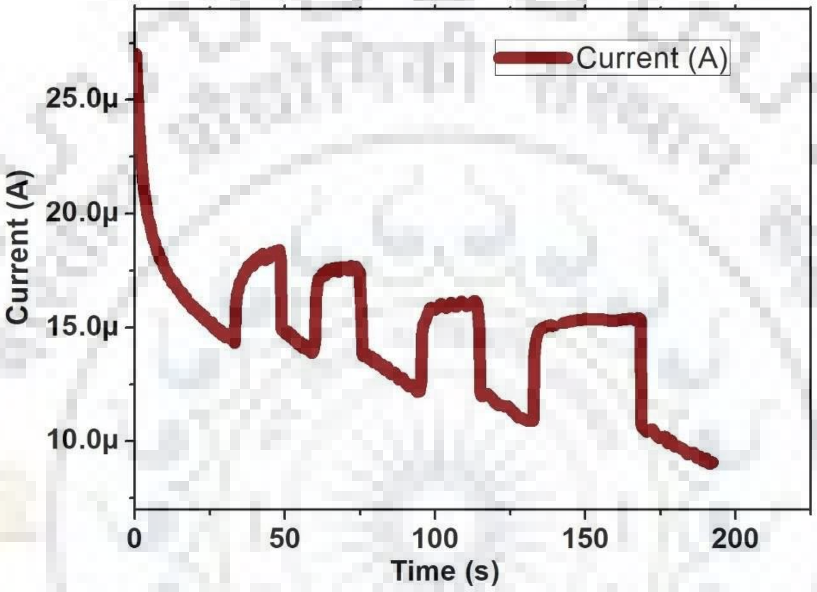


Fig 25.

Experimental Details – ZnO -T films deposited on interdigitated pattern is kept under observation. Light is made to incident on the specimen and current changes are recorded in real time.

Analysis – As shown in the graph, current increment is seen when light is allowed to fall on the film and drops when removed. This shows photosensitive behavior of ZnO-T films like that of a photo diode.

CHAPTER 5 CONCLUSION AND FUTURE SCOPE

5.1 Conclusion

The current study concluded that ZnO-T is sensitive towards ethanol, hence can be used for ethanol detection purposes. Ethanol exposure shows change in the electrical properties of ZnO-T immediately or in real time itself. It decreases the resistance of the film thereby allowing more current to pass through. It causes substantial change in the conductivity of the material.

Sensitivity of sensor also depends

ZnO-T can be a really good alternative for ethanol detection though currently it was not found to show better sensitivity or selectivity than the commercially available SnO2 based sensors.

Continuity in the structure is still a challenge for the current flow to be uninterrupted which is significantly rectified by the interdigitated electrodes patterns.

It is sensitive to light as well so can be even used for light detection applications.

5.2 Scope of Future work

Gas sensing device in which ZnO-T layer is the sensing material can be designed which can be utilized for ethanol vapor sensing. Solubility of ZnO-T structure in proper nonpolar solvent can be worked upon so that better films can be made out of it. Its sensitivity and selectivity can be modulated by doping several other materials of compatible size and electrical sensing properties.

It can also be used as photo diode or can be used in solar cell applications as it is responsive to light.

A multipurpose sensor which is sensitive to ethanol and light can be designed and its sensitivity towards other gases or vapors of interest can be investigated.

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