DISSERTATION

ON

GROWTH OF SnO2 LAYER FOR UV PHOTODETECTOR

under the guidance
of Dr. R.Thangavel

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Date: November 12, 2024.

CERTIFICATE

*Certified that the work presented in the dissertation entitled "**Growth of SnO2 layer for UV Photodetector**" is an authentic record of the research work carried out by **Mageshan Kp** under my supervision in partial fulfillment of the requirement for the degree of **B. TECH.** in **ENGINEERING PHYSICS** of the Indian Institute of Technology (ISM) Dhanbad during the Monsoon semester (Aug. 2024 to Nov. 2024). Further that no part of this dissertation has been presented previously for the award of any other degree.*

Approved and forwarded by

Dr. R.Thangavel
(Supervisor)

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Abstract

In this report, I have discussed the SnO_2's potential as a material for UV photodetection, focusing on its properties, advantages, and applications in UV-sensitive devices. Beginning with an overview of photodetectors and the critical role of UV detection in fields like environmental monitoring, healthcare, and defense, SnO_2's wide bandgap, UV transparency, and excellent stability make it highly suitable for UV photodetection, enhancing device efficiency and durability.The experimental section outlines the synthesis of SnO_2 nanoparticles, covering the methodology and key reactions for producing optimized particles for UV detection. Overall, SnO_2 shows great promise in improving UV photodetector performance, combining an ideal bandgap with structural stability to meet modern UV detection demands. Future work will involve various characterization techniques and device fabrication.

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Contents

Chapter 1

Introduction

1.1 Photodetectors

Photodetectors operate on the **principle of photoelectric effect**, where incident photons (light particles) are absorbed by the material, generating a measurable electrical signal. This process can occur through various mechanisms depending on the type of photodetector and material. For SnO_2 UV photodetectors, the process generally follows the **photoconductive** or **photovoltaic** effect:

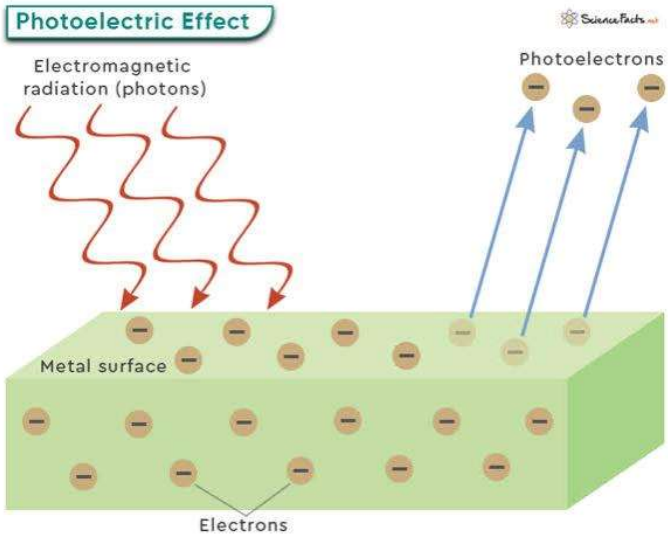

Figure 1.1: Photoelectric effect

1. Photoconductive Effect

- When UV photons hit the SnO_2 photodetector, they provide enough energy to excite electrons from the valence band to the conduction band (since SnO_2 has a wide bandgap suitable for

UV).

- This excitation generates electron-hole pairs, increasing the number of free charge carriers (electrons and holes).
- The presence of these extra carriers enhances the material's electrical conductivity, which can be measured as a change in current when an external voltage is applied.
- The increase in conductivity is directly proportional to the intensity of the UV light, so a stronger UV light results in a larger current change.
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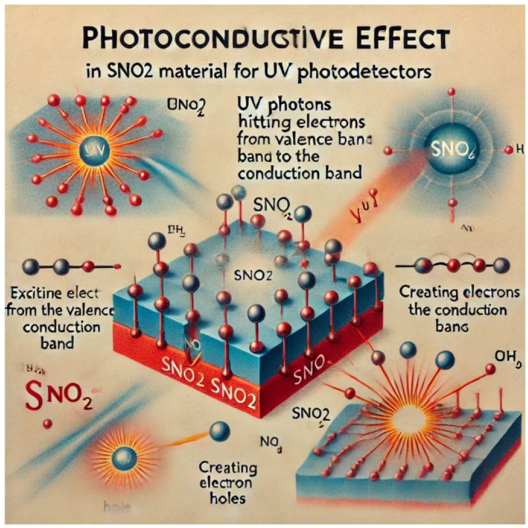

Figure 1.2: Photoconductive effect

2. Photovoltaic Effect

- In some photodetectors, including those designed as p-n junctions, the photogenerated electron-hole pairs are separated by an internal electric field within the junction.
- The electrons and holes move towards opposite electrodes, creating a voltage across the

device without an external power source.

- This photovoltage is then measured and is also proportional to the intensity of the incident UV light.

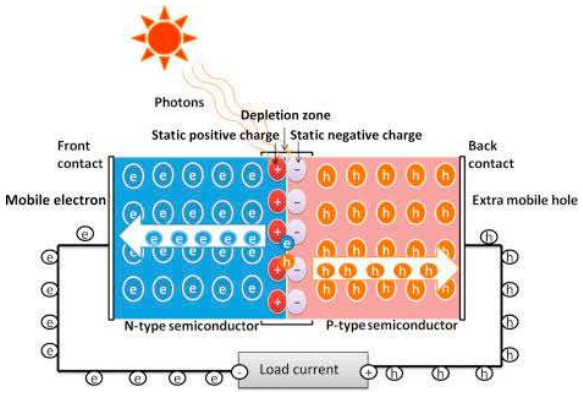

Figure 1.3: Photovoltic effect

Key Elements in Photodetection:

- **Absorption of Light**: Only photons with energy equal to or greater than the bandgap of the material (3.6 eV for SnO_2) can excite electrons, which is why SnO_2 is selective to UV light.
- **Carrier Generation and Separation**: The absorption of UV photons creates electron-hole pairs that are either separated by an applied or internal electric field.
- **Current or Voltage Measurement**: The generated carriers change the current (in photoconductive detectors) or produce a photovoltage (in photovoltaic detectors) which is then measured to detect the presence and intensity of UV light.

This principle of converting light into an electrical signal is what enables SnO_2 and other photodetectors to detect and measure UV radiation in various applications.

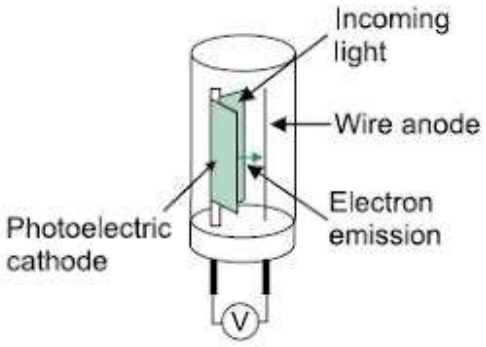

Figure 1.4: Photodetector

1.2 UV Spectrum and UV Photo detectors

UV photodetectors are specialized devices designed to detect ultraviolet (UV) radiation, which spans the wavelength range of approximately 10–400 nm. This spectrum is generally divided into three regions:

• UV-A (320–400 nm) – Least energetic and penetrates through glass; used in medical applications.

• UV-B (280–320 nm) – Causes sunburn and is partially absorbed by the atmosphere.

• UV-C (100–280 nm) – Most energetic and almost entirely absorbed by Earth's atmosphere; used in sterilization.

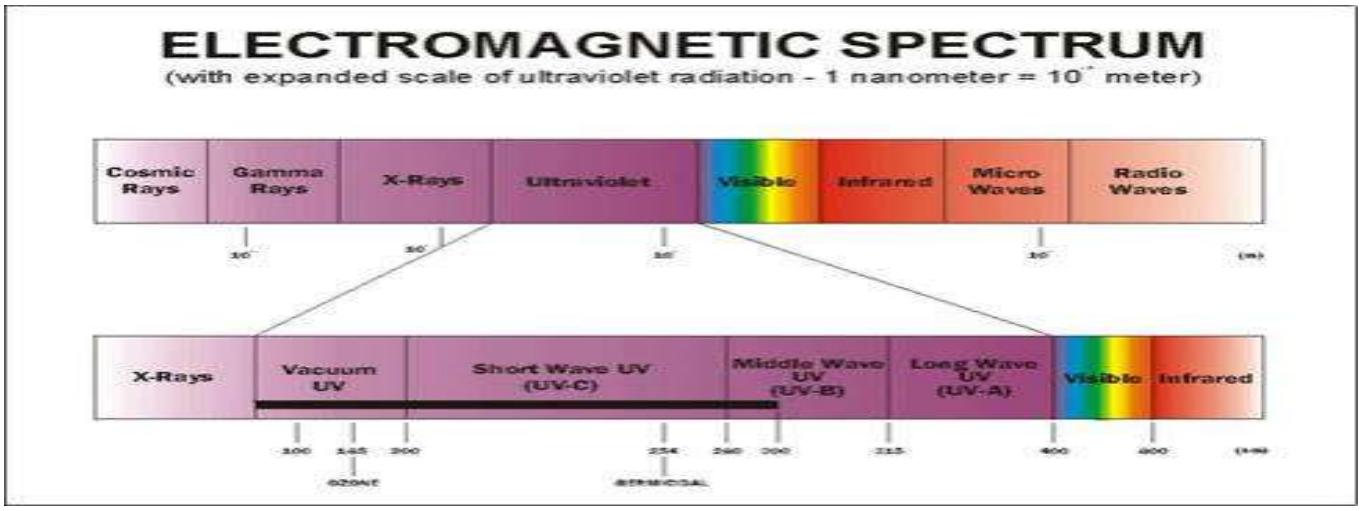

Figure 1.5: UV spectrum

Chapter 2

Theoretical framework

2.1 Properties of SnO2

Formula: SnO_2

Crystal Structure: Rutile-type tetragonal structure, similar to TiO_2.

Bandgap: Wide bandgap of ~3.6 eV at room temperature, making it a good candidate for UV applications.

Color and Appearance: White or colorless in powder form; transparent when thin-film.

Density: 6.95 g/cm³.

Stability: High thermal stability; stable up to ~600 °C.

Electrical Properties: Generally an n-type semiconductor due to oxygen vacancies, which act as electron donors.

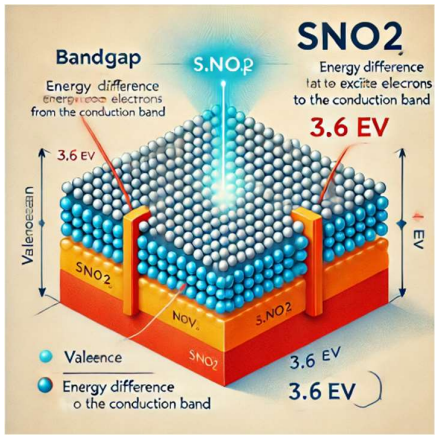

Figure 2.1: Bandgap of SnO2

2.2 SnO2 as a material for UV Photo detection

Tin Oxide (SnO_2) is a widely studied material in the field of UV photodetection due to its unique combination of optical and electronic properties. Here's a look at why SnO_2 is advantageous for UV detection:

1. **Wide Bandgap (~3.6 eV)**:
    - SnO_2 has a wide bandgap of approximately 3.6 eV, which makes it responsive to UV light, particularly in the UV-A and UV-B ranges, while filtering out most visible and infrared light. This property ensures that SnO_2-based photodetectors have high UV selectivity and avoid interference from other parts of the light spectrum, an essential feature for accurate UV detection.
    -
2. **High Transparency in the UV Region**:
    - SnO_2 is highly transparent to UV light, allowing photons to pass through and generate a strong photocurrent within the material. This high transparency enhances the material's UV sensitivity, which is especially useful for detecting faint or low-intensity UV signals in applications that require precision.
    -
3. **Thermal Stability**:
    - SnO_2 is thermally stable, which allows it to function reliably at elevated temperatures without degradation. This stability makes SnO_2 photodetectors ideal for applications in extreme environments, such as industrial processes, space exploration, or areas exposed to strong sunlight, where materials with lower thermal stability may fail.
    -
4. **Chemical Stability**:
    - SnO_2 is resistant to corrosion, oxidation, and many chemical reactions. This chemical stability enables long-lasting performance in challenging environments, such as those involving pollutants, moisture, or reactive chemicals. This property is particularly valuable for outdoor UV monitoring or industrial applications where environmental exposure is a concern.

2.3 Advantages of SnO2 in UV Photodetectors

- **Cost-Effectiveness**: SnO2 is widely available and relatively inexpensive, which can make SnO2-based UV detectors more economical for mass production.
- **Fast Response Times**: SnO2's good electron mobility and conductivity enable rapid response times in UV detection, crucial for applications that need real-time monitoring.
- **Low Dark Current**: SnO2 typically exhibits low leakage or dark current, which results in a higher signal-to-noise ratio, allowing for precise detection even at low UV intensities.

Figure 2.2: Stannous Chloride

Chapter 3

Experimental framework

3.1 Basic outline of the experimental framework

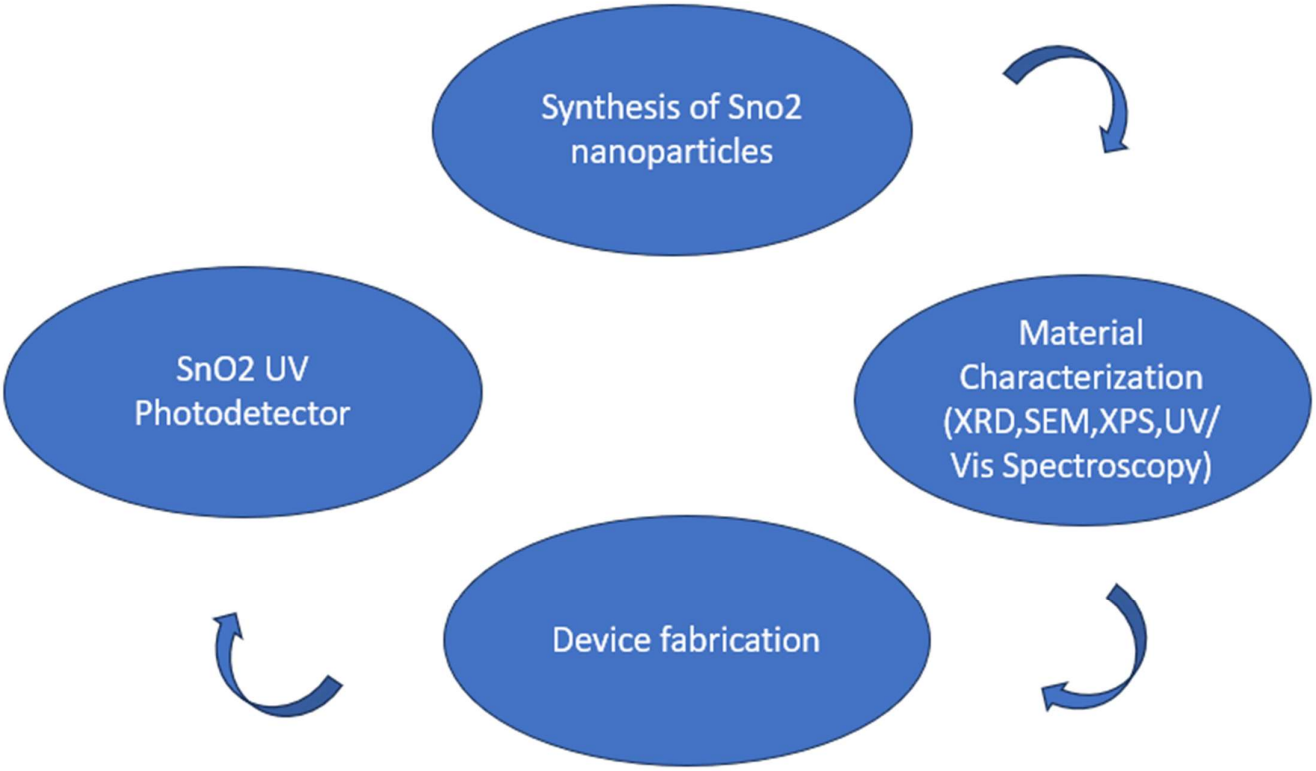

Figure 3.1: basic outline of experimental framework

3.2 Methodology used for the synthesis of SnO2 nano particles

SOL GEL METHOD

Precursor – **$SnCl_2 \cdot 2H_2O$**

molar mass of **$SnCl_2 \cdot 2H_2O$** -- 118.71+70.9+36.03 = **225.64**g/mol

molarity = 0.5 M , Volume = 20 mL = 0.02 L

moles of SnCl2·2H2O = 0.5 M × 0.02 L = 0.01 moles

Mass of $SnCl_2 \cdot 2H_2O$ required = 225.64 × 0.01 = **2.256 g**

Solution Preparation:

Dissolve 1.128g of **$SnCl_2 \cdot 2H_2O$** (stannic chloride hydrate) in a 20 ml ethanol-water solution (1:1 ratio).

Stirring:

Stir the solution for about 20 minutes until a transparent sol forms.

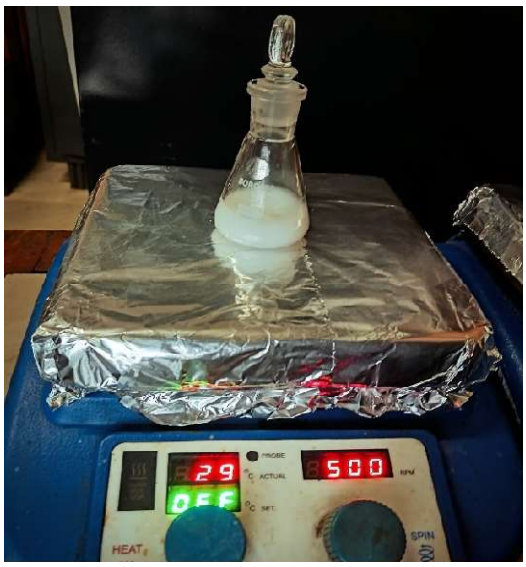

Figure 3.2: Stirring image

pH Adjustment: Add aqueous ammonia (25%) drop by drop while stirring constantly, adjusting the pH to around 8.

Figure 3.3: PH adjustment

Aging: Allow the sol to age in air for 24 hours, forming an opal gel.

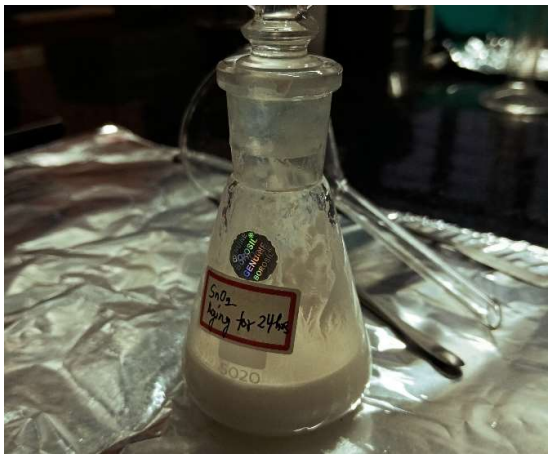

Figure 3.4: aging

Centrifugation and Washing: Centrifuge the gel and wash it with ethanol at least 5 times to remove ammonia and chloride impurities.

Drying: Dry the collected gel at 80°C for 4 hours to remove moisture.

Figure 3.5: drying

Sintering: Crush the dried sample and sinter it at 500°C for 4 hours. This step results in ash-colored SnO_2 nanoparticle powder.

Figure 3.6: SnO2 nanoparticle powder

3.3 Chemical reactions involved in the process

Step 1: Dissolution of $SnCl_2 \cdot 2H_2O$ in Ethanol-Water Solution

When tin(II) chloride dihydrate, $SnCl_2 \cdot 2H_2O$, is dissolved in a mixture of ethanol and water, it dissociates into Sn^{2+} ions and chloride ions:

$$SnCl_2 \cdot 2H_2O \rightarrow Sn^{2+} + 2Cl^- + 2H_2O$$

Step 2: Hydrolysis of Sn^{2+} to Form Tin Hydroxide

When ammonia (NH_3) is added, it increases the pH of the solution, leading to the hydrolysis of Sn^{2+} ions to form tin(II) hydroxide:

$$Sn^{2+} + 2NH_3 + 2H_2O \rightarrow Sn(OH)_2 \downarrow + 2NH_4^+$$

This reaction forms a precipitate of tin(II) hydroxide, $Sn(OH)_2$.

Step 3: Dehydration and Conversion to SnO_2

Upon drying and heating, the $Sn(OH)_2$ undergoes dehydration and converts to tin(II) oxide (SnO) and then oxidizes further to tin(IV) oxide (SnO_2):

1. **Dehydration:**

$$Sn(OH)_2 \rightarrow SnO + H_2O$$

2. **Oxidation:**

$$2SnO + O_2 \rightarrow 2SnO_2$$

The final product after sintering is **SnO_2,** which is the desired nanocrystalline material.

Pictorial representation of synthesis

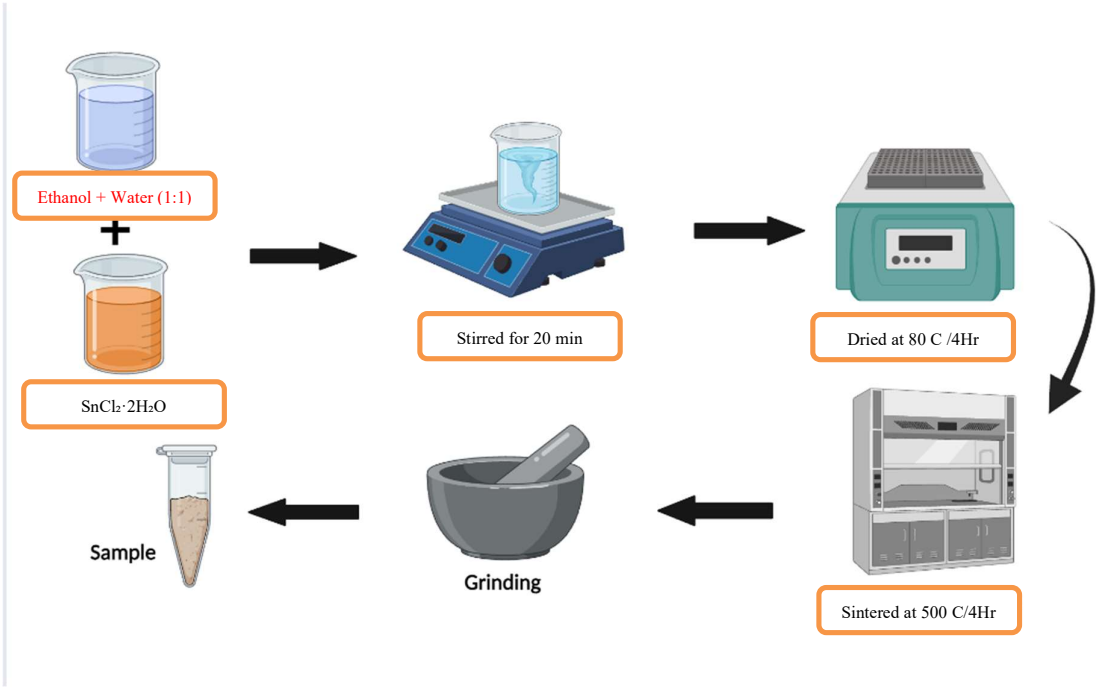

Figure 3.7: Pictorial representation of synthesis

Chapter 4

Conclusions

4.1 Conclusions

In this report, I have discussed the potential of SnO_2 as a material for UV photodetection, covering its fundamental properties, advantages, and application in UV-sensitive devices. We began with an introduction to photodetectors and the specific role of UV photodetectors, emphasizing the importance of detecting UV radiation in fields like environmental monitoring, healthcare, and defense.

SnO_2, with its wide bandgap, high transparency to UV light, and excellent thermal and chemical stability, emerges as a superior material for UV photodetection. We reviewed the specific properties that make SnO_2 advantageous, particularly for UV sensitivity, and how these characteristics contribute to device efficiency and durability.

Furthermore, the experimental framework provided an overview of the synthesis of SnO_2 nanoparticles, detailing the methodology and key chemical reactions involved in producing nanoparticles with optimized properties for UV detection.

Overall, SnO_2 demonstrates significant promise for enhancing UV photodetector performance, with its combination of ideal bandgap and structural stability offering robust solutions for modern UV detection applications.

Future work may expand on working through various characterization techniques that I have mentioned below and till device fabrication.

Characterization techniques to be followed

XRD

Figure 4.1: XRD

SEM

Figure 4.2: FESEM

XPS

Figure 4.3: XPS

Figure 4.4: UV/VIS Spectroscopy

DEVICEFABRICATION

Figure 4.5: spin coating unit

Figure 4.6: IV Characteristics

References

[1] Synthesis and characterisations of SnO2 nanorods via low temperature hydrothermal method Vicinisvarri Inderan a, Shin Ye Lim a, Teng Sian Ong b, Samuel Bastien c, Nadi Braidy c, Hooi Ling Lee a,*D. Aadim, K. Ahmed, and R. Mohammed, "Diagnostic analysis of cu and cuzn plasma produced by nd: Yag nanosecond laser at 1064 nm," vol. 2372, p. 080018, 11 2021.

[2] Synthesis of SnO 2 Thin Film by Sol-gel Spin Coating technique for Optical and Ethanol Gas Sensing ApplicationP. McKenna, D. Neely, R. Bingham, and D. Jaroszynski, *Laser-plasma interactions and applications*. Springer, 2013.

List of Figures