GROWTH AND CHARACTERIZATION OF TIN (II) OXIDE (SnO) THIN FILMS AT 0.12 MOLARITY AND ROOM TEMPERATURE FOR DIFFERENT DEPOSITION TIMES AND THEIR POSSIBLE INDUSTRIAL APPLICATIONS

BY

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UNIVERSITY OF BENIN
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CERTIFICATION

I hereby certify that I approve the following research essay adequately performed in the Department of Physics under the supervision in scope and quality for the partial fulfillment of (B.Sc.) Hons) Degree in Industrial Physics.

PROF C.O AIGBOGUN	**DATE**
(Head of Department).	
PROF P. O. ILENIKHENA	**DATE**
(Project Supervisor).	
EXTERNAL EXAMINER	**DATE**

DEDICATION

This project work is dedicated to My Father in heaven for His protection, Guidance, and giving me understanding throughout my four-year educational span in the University of Benin, and to my family for their prayers, advice, love and support.

CERTIFICATION OF DISSERATION ON PLAGIARISM

We the undersigned, attest to and declare that the dissertation of Monday Igbinomwanhia Osazee titled "Chemical Bath Deposition and Characterization of Tin ll Oxide (SnO_2) Thin Films at 0.12 Molarity and Room Temperature for Different Deposition Time and Their Possible Applications" has successfully passed the anti-plagiarism test and does not violate any copyright regulation.

______________________________	___________________________
PROF P.O. ILENIKHENA (Project Supervisor)	**DATE**
______________________________	___________________________
PROF C.O AIGBOGUN (Head of Department)	**DATE**

ACKNOWLEDGEMENT

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Finally, I want to express my gratitude to my lecturers and colleagues for the sacrifices they have made thus far.

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ABSTRACT

Tin (ll) oxide was successfully deposited on glass based at room temperature using an amplified Solution Growth Technique (SGT) at a concentration of 0.12 molarity for different lengths of time (12, 18, 24, 30 and 36hrs). The glass slides went to degreasing by being submerged in concentrated Hydrochloric acid for three days, then it was rinsed in distilled water and was main goal was air dried. A T80+ UV/VIS Double beam spectrophotometer was made use of to obtain Absorbance spectra (A) within the wavelength spectrum ranging from 202 to 315nm. The optical properties and solid-state characteristics of the films were calculated from the result gotten and mixed against other deposited thin films. The average optical and solid state properties includes: absorbance (A) = 0.658 - 0.551, transmittance (T) = 0.222 - 0.281, Reflectance (R) = 0.564 - 0.730, absorbing power =5.85 x 10^6 - 4.99 x $10^6 m^{-1}$, Refractive index (n) = 7.032 - 12.736, Film thickness (t) = -0.073 - (-0.063) and bandgap (Eg)= 4.754 - 4.693eV. The deposited films within light range (≈4.0-5.0eV) finds application in Solar Cells for high energy photons: materials with wider bandgap can capture high energy UV photons, potentially increasing the efficiency of solar cells to improve the standard of living in rural areas.

CHAPTER ONE

1.0 INTRODUCTION

Traditional energy sources are the commonly used types of energy sources. From the beginning of time these energy sources have been implemented and they include; coal, oil, electricity and natural gases.

The need for fossil fuels and electrical energy is rising rapidly and has become difficult to get fresh supply. Each time fossil fuels are found, they are found to be smaller than those that have already been discovered.

A good example would be power grids. In the case of power grids: It has been discovered that a lot of power outages occur in grid stations causing grid instability, power grids also have high maintenance issues as maintaining these grids are very costly.

Another good example would be oil reserves. It's known that 16 of 20 of the largest oil reserves are not enough to meet worldwide demands and as a result, the world's oil reserves will soon be depleted. Although our known coal deposits may last for a couple of years, it will quickly disappear if the need to produce more fossil fuels increases.

As a result, the world is using solar energy as a source of power as finding fresh reserves of fossil fuels is becoming more difficult. In recent times solar energy has become a major source of power.

In localities where electrical energy and fossil fuels do not generate enough power, solar energy has stood as a suitable replacement as it is noise free, environmental friendly and pollution free.

Finding alternative sources to produce energy should be the top priority for the entire world as they are the most affordable and environmentally friendly way to produce energy.

For this purpose, thin film technology has been introduced, which is key for converting solar energy into heat or electrical power. Thin films could be deposited on a glass or metallic substrate using different methods.

For this purpose, the Solution Growth Technique would be considered.

1.1 LITERATURE REVIEW

Thin films are layer of material with thickness that range from a few nanometers to several micrometers. They are typically applied to a surface using various deposition methods which is an essential step. One common example of thin films is a household mirror, which usually consists of a tiny layer of metal coated to create a reflective surface on the back of a glass sheet. These transparent, thin films are used in a variety of procedures, such as solar energy conversion. Solar energy collectors use anti-reflection coatings made of thin films with thickness of less than 100nm. Thin films are used in industries for a variety of optical coatings, reflection-increasing films, fluorescent coatings and multi-layer interference filters.

Throughout the 20th century, developments in thin film deposition techniques have made it possible to achieve several technical advancements in fields including magnetic recording media, electronic semiconductor devices, LED's, integrated passive devices and thin-film batteries for energy production and storage.

In electronics, thin films are used in photo-emissive surfaces, piezoelectric transducers, passive and active electronic components from transistors or resistors networks to such specialized devices as photo sensors, storage bits and cryotrons (Ilenikhena, 2000).

The method and techniques used for preparing these thin films depends on the substrate coating materials which can range from simple and cheap to more complex and expensive, these preparations also depend on the required performance of the films (Quidaja, et al, 1998, Chopra, 1969).

Various reasons have led to research in this field, including Solution Growth Techniques (SGT), as well as research of temperatures, concentrations, deposition times and even the characteristics of the material deposited and its processes.

Tin (II) oxide is a compound that can be used to create thin films for various purposes such as

1.2 CHOICE FOR SOLUTION GROWTH TECHNIQUE

- It is cost effective and easy to carry out
- Less casualty is encountered
- It does not depend on any form of electricity
- It is environmentally friendly

1.3 AIM AND OBJECTIVES

1.3.1 AIM

The aim of this work is to grow tin (II) oxide (Sn0) using improved solution growth technique at 0.12 molarity and room temperature for different deposition times of 12, 18, 24, 30, and 36 hrs.

1.3.2 OBJECTIVES

The objectives of this work are to:

- obtain the optical and solid state properties of the tin (II) oxide thin film grown.
- to identify the possible applications of the thin films on the basis of their properties.

CHAPTER TWO

2.0 THEORY

2.1 SOLAR RADIATION

Solar radiation is the electromagnetic radiation that is emitted by the sun including visible and invisible light which is known as sunlight. It is a constant source of natural energy that travels in all directions through space as electromagnetic waves. Solar radiation can be captured and turned into useful forms of energy, such as heat and electricity using various technologies.

Solar radiation is a high-temperature, high-energy energy source at its origin, the Sun, where its irradiance is about 63 MW/m2. However, Sun–Earth geometry dramatically decreases the solar energy flow down to around 1 kW/m2 on the Earth's surface.

Nevertheless, under high solar flux, this disadvantage can be overcome by using concentrating solar systems which transform solar energy into another type of energy (usually thermal).

The earth revolves around the sun in an elliptical orbit. When the sun is nearer to the earth, the earth’s receives more solar energy. However the presence of oceans moderates the hotter environments.

2.1.1 SOLAR RADIATION INTERACTION WITH THE EARTH’S ATMOSPHERE

According to physics, solar radiation interacts with the earth’s atmosphere in several ways including: absorption, scattering and reflection.

Absorption is the process where the earth’s surface and it’s atmosphere capture energy from the sun, converting it into heat.

Scattering is the process where sunlight is redirected in various directions as it passes the Earth’s atmosphere, bouncing off different atmospheric components. Scattering is useful for creating phenomena like blue colour of the sky.

Reflection refers to the process where incoming solar radiation bounces back from a surface of the Earth without being absorbed, this is measured by the Earth’s albedo which indicates how much solar radiation is reflected by the surface.

The radiation from the Sun consists of a broad range of ultraviolet (UV), visible light, and infrared radiation all traveling at the speed of light (about 3 x 108 meters/second) through the vacuum of space. Atmospheric molecules like water vapour, oxygen, and aerosols absorb about 15% of the sun’s radiation. Some of the heat absorbed is emitted as longwave infrared radiation, which radiates into space.

Because the earth is significantly cooler than the sun, it emits longer wavelength radiation.

2.2 SOLAR RADIATION INCIDENT ON SURFACE

Solar radiation incident on surface refers to how much solar radiation strikes a surface at an angle of 90℃. The amount of solar radiation that reaches the surface after changing direction due to atmospheric scattering is known as Diffused Radiation. A device known as the pyranometer is used to measure the amount of solar radiation falling on a surface, the amount of solar radiation falling on any spot on the Earth's surface varies with respect to:

- Season
- Local weather
- Time of day
- Landscape
- Geographic location

Due to the Earth elliptically orbiting around the sun, it gets closer to the sun during part of the year, especially when it is winter in the northern hemisphere and summer in the southern hemisphere. Because of this, the Earth receives more solar energy.

The Earth's rotation causes hourly changes in sunlight. In the sky sun is low in the morning and afternoon. Compared to midday, when the sun peaks, it's radiation penetrates the atmosphere furthermore.

2.2.1 SELECTIVE SURFACE

7% of the Sun's radiation is ultraviolet,having wavelengths between 0.3 and 0.4 micrometers. The visible light spectrum is about half: 48% of the Sun's energy falls between 0.04 and 0.7 micrometers. The rest of the radiation is 45% infrared, from 0.7 to 0.4 micrometers, including near-infrared light and stretching into far infrared. This blend of wavelengths is necessary for everything from heating the Earth to powering solar technologies.

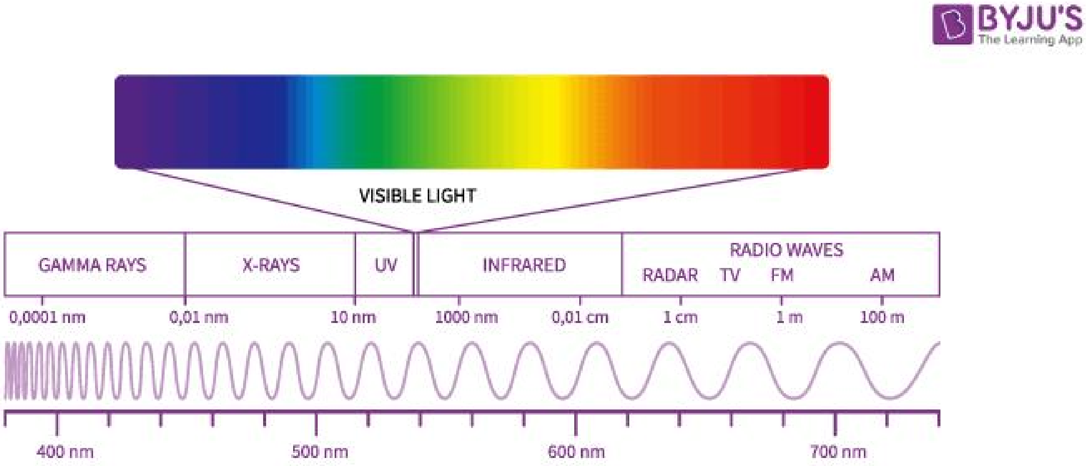

Fig 2.1: Image showing the types of radiation in the electromagnetic spectrum grouped by their wavelength.

Every object, as long as it is above the absolute zero value(-273.15℃), which is the lowest temperature, radiates energy into its surrounding environment. This energy travels as electromagnetic waves moving at the speed of light. The wavelength from electromagnetic radiation can range from being infinitely short to infinitely long.

The sun emits around 7% of its total energy which is ultraviolet with wavelengths between 0.3-0.4mm. The radiation from the visible light spectrum is almost half; about 48% of the

Sun’s energy with wavelengths of about 0.4-0.7mm. The infrared comprises of the remaining 45% of the Earth’s total energy with wavelengths of 0.7-0.4mm, including near-infrared light and stretching into far infrared.

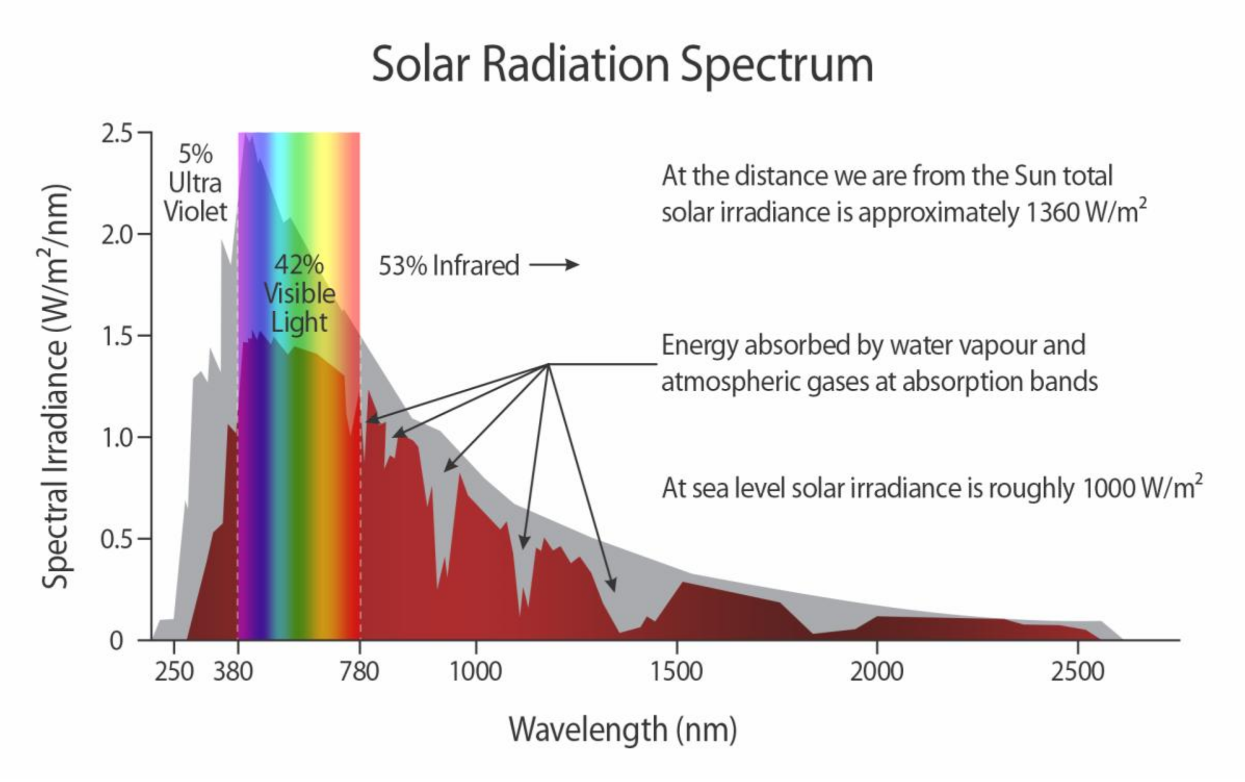

Fig 2.2: Solar radiation spectrum; Graph of spectral irradiance against wavelength

2.3 OPTICAL AND SOLID STATE PROPERTIES

The following optical properties computed in this work are;

- Absorbance (A)
- Reflectance (R)
- Transmittance (T)

- Absorbing power or coefficient of absorption (α)
- Refractive index (n)

The solid state properties include:

- Film thickness (t)
- Bandgap (Eg)

2.3.1 ABSORBANCE (A)

Absorbance is defined as the logarithm ratio of incident to transmitted radiant power through a sample. It is given by the formula:

$$A = \log_{10}(\frac{1}{T}) \qquad (2.1)$$

The absorbance (A) is typically derived directly from measurements of absorption spectra and further properties are derived from calculations based on them.

2.3.2 TRANSMITTANCE (T)

Transmittance is defined as the proportion of radiant power transmitted by a body to the total power incident on the body. It is given by the formula:

$$T = \frac{l}{l_0} \qquad (2.2)$$

Where l_0 is the total incident radiant power and I is the radiant power that is being transmitted

Since transmittance and absorbance are logarithmically proportional in equation (2.1)

$$T = 10^{-A} \qquad (2.3)$$

2.3.3 REFLECTRANCE (R)

Reflectance can be defined as the ratio of light reflected from a material when it is incident perpendicularly to that which is reflected from a standard with known reflectance. It is given by the formula

$$A + T + R = 1 \tag{2.4}$$

2.3.4 ABSORBING POWER OR COEFFICIENT OF ABSORPTION (α)

The absorbing power or coefficient of absorption (α) is the ability of a material to absorb energy while the energy is passing through the material or striking the surface. It is that fraction of incident energy (light, sound, heat) which is absorbed by the material and not reflected or transmitted. Absorbing power depends on the type of material, the wavelength of the incoming energy, and environmental conditions.

According to Cothian, 1958 and Wooten, 1972, the absorption coefficient (α) of the flux's propagation through the material is provided if l_o is the incident flux and l is the emerging flux through a medium of thickness t. It is expressed by the equation:

$$I = I_0 e^{-ax} \tag{2.5}$$

From equation (2.1) and (2.5), the transmittance (T) and coefficient of absorption (α) are conveyed by:

$$T = exp^{(-\alpha t)} \tag{2.6a}$$

$$\therefore \ \alpha = (lnT^{-1}) \tag{2.6b}$$

Where a unit distance travelled, t = 1

Then,

$$\alpha = ln(T^{-1}) \ \mu m^{-1} \tag{2.7}$$

Where μ is linear absorption coefficient (10^{-6} m^{-1}or cm^{-1})

2.3.5 REFRACTIVE INDEX (n)

The refractive index (or refraction index) of a medium is the ratio of the apparent speed of light in the air or vacuum to the speed in the medium. The refractive index determines how much the path of light is bent, or refracted, when entering a material. This is described by Snell's law of refraction

The expression for the reflectance (R) normal to the surface relating to optical constants n and k is given by:

$$R = [(n-1)^2+K^2] \backslash [(n-1)^2+K^2] \qquad (2.8a)$$

Where ***K*** is the extinction coefficient for semiconductors,

$$K^2<<(n+1)^2 \qquad (2.8b)$$

Equation (2.8) therefore reduces to:

$$R = (n-1)^2 / (n+1)^2 \qquad (2.8c)$$

From equation (2.10), we have:

$$n = (1+R^{1/2}) / (1-R^{1/2}) \qquad (2.8d)$$

2.3.6 BANDGAP (Eg)

In solid state physics, a band gap energy generally refers to the difference of energy between the top of the valence band and the bottom of the conduction band. The bandgap’s width is a highly significant characteristic of semiconductors and is usually represented by Eg.

In crystalline materials, there are four types of electron transitions: Direct transition, direct permitted transition, directly forbidden transition, and indirect transitions.

The general expression for direct transition is:

$\alpha = (hv - Eg)^n$ (2.9)

Where $n = \frac{1}{2}$ for direct permitted transition between valence and conduction bands

And $n = \frac{3}{2}$ for directly forbidden transitions

Indirect transitions can be expressed as;

$\alpha = (hv - Eg)^{\frac{1}{2}}$ (2.9b)

Or

$\alpha^2 = hv - Eg$ (2.9c)

Where hv = photon energy

The photon energy E(J) for a given wavelength λ is given by:

$$E(J) = hv(J) = hc/\lambda(J) \quad (2.9d)$$

Where h = Planck's constant (6.62 x 10^{-34} Js,

C = velocity of light = 3×10^{8} ms^{-1}

λ = wavelength in meters

Equation 2.15 gives:

$$hv(J) = \frac{(6.62 \ x \ 10\text{^}{-34} \ x \ 3x10\text{^}8)}{\lambda}$$

But 1 eV = 1.6 x 10^{-19}

$$\therefore \quad hv(eV) = \frac{(1.986 \ x \ 10^{-16})}{\lambda} x \ 1.6 \ x \ 10^{-19}$$

= 1241 \ λ (nm) (2.9e)

Equation 2.9e is used to calculate the photon energy (hv) in eV for a variety wavelength (λ) in nm.

2.4 THIN FILMS

A thin film is a layer of materials ranging from fractions of a nanometer to several micrometers in thickness. A typical example is the household mirror.which typically has a thin metal coating on the back of a sheet of glass to form a reflective interface. The process of silvering was once used to produce mirrors, recently the metal layer is deposited using techniques such as sputtering.

One of the main characteristic of thin film materials is their dependence on growth technologies. This category of materials is relevant when considering energy applications, which include, magnetic recording media, electronic semiconductor devices, integrated passive devices, light-emitting diodes, optical coatings.

It is also being applied to pharmaceuticals, via thin-film drug delivery. Thin film medication delivery is another way thin films are being used in the field of medicine.Thin film technology is a conventional technology, but according to the demand of the 21st century, the development of new technologies is still evolving. In order to create semiconductor devices, thin films of various materials must be formed by deposition method. This industry is only concerned with thin film creation.

In addition to their applied interest, thin films play an important role in the development and research of materials with new and distinctive properties. Examples include multiferroic materials, and superlattices that allow the study of quantum processes.

2.4.1 THIN FILM DEPOSITION METHOD

Various methods of deposition are used for synthesizing thin films which each have their strengths and limitations. Among the several methods includes the most commonly used methods such as;

- Sputtering,
- Chemical Vapour Deposition,
- Sol-Gel, and
- Chemical Bath Deposition (CBD).

Among these various deposition methods, Chemical Bath Deposition (CBD) is the most commonly used method for its simplicity and cost-effectiveness.

2.4.2 CHEMICAL BATH DEPOSITION (CBD) METHODS

Chemical bath deposition (CBD) is a process that involves the use of a soft solution to produce high-quality thin films at low temperatures. This technique is widely used to grow materials in thin film geometry with thicknesses ranging from a few nanometers to several microns.

From ancient times, chemical bath deposition (CBD) is the most extensively used method for the synthesis of the thin film. This method was reported in 1884 by Reynolds et al. For the creation of thin films and coatings of a very wide range of materials necessary for advanced technology, deposition technology has emerged as one of the most significant method.

As a technique for depositing thin nonmetallic inorganic films from aqueous solutions, chemical bath deposition is at least 140 years old. This technique has become popular for the preparation of thin films by immersion of a substrate into a chemical solution, onto whose surface the material slowly deposits. It is also popular due to its simplicity and low cost.

The fundamental properties of CBD are reduction, oxidation ,nitridecarbide production, chemical transport, hydrolysis, pyrolysis and disproportation. The rate of deposition and the characteristics of the thin film deposits are controlled by variables such as pressure, input concentrations, gas flow, operational principles, rector geometry and temperature.

The general mechanism of CBD uses controlled precipitation of any material from its solution. This occurs when the temperature or pH conditions of the solution lower the solubility of the material of interest, hence allowing nucleation to take place and gradual growth onto the substrate. This process is a three-stage process, and the first step involves nucleation at which small clusters of the material form on the surface of the substrate. The next stage in the process involves the clusters becoming larger by the continuous precipitation and attachment of more material. The process is completed when the surface becomes saturated or the reactants in the solution are exhausted (Kale and Lokhande, 2005).

CBD has emerged as a crucial process technology I numerous industrial sectors. It is crucial in the applications in solid-state microelectrics. In metallurgical applications, corrosion resistant coatings are employed to safeguard metals.

CBD has various advantages to its credit, which makes this mode of treatment so popular.It is cost-effective and doesn't require expensive equipment or complex high-vacuum systems, making it accessible for both research and large-scale industrial use. The process can also be scaled up to deposit films over large areas or on substrates with intricate shapes. Furthermore, the low-temperature nature of CBD makes it ideal for materials that might not withstand high temperatures, like polymers or flexible substrates (Lokhande et al., 1999).

2.4.3 ADVANTAGES OF CHEMICAL BATH DEPOSITION

Chemical bath deposition (CBD) is a process that involves the use of a soft solution to produce high-quality thin films at low temperatures. This approach is used consistently for the following reasons;

- The cost of operation is lower than the other deposition methods (chemical vapour deposition, e.t.c.).
- It can be deposited on different substrates, Eg, glass, ceramics, e.t.c
- It is suitable for large scale thin film deposition operations.
- It can be used in coating irregularly shaped substrates surfaces with ease.

Additionally, CBD stands out because it is a low-cost deposition technique, easy to use, and versatile, making it a suitable method in large scale operation in industries.

2.5 THIN FILM MEASUREMENTS AND TECHNIQUES

Thin films need to be measured and analyzed in order to prove that they truly have desirable properties and are functioning well for certain applications. The effectiveness of thin films are greatly influenced by measurements of thickness, optical and solid state. The methods used to measure thin films range from very basic chemical and mechanical procedures to complex electrical and spectroscopic ones. Some of the techniques used to measure thin films are;

- Gravimetric method
- Spectroscopic method
- Spectrophotometric method
- Profilometric method

- Adhesion testing method

2.5.1 MEASUREMENT OF THIN FILM THICKNESS

Measurement of thin films thickness is critical in various scientific and industrial applications including, electronics, optics, and material science. Thin films which can range from just a few nanometers to several micrometers thick, play a key role in determining the performance of devices and materials. Optical methods like, ellipsometry and absorption spectroscopy can be used to quantify thickness. The following is a breakdown of the two common methods used to measure thin films thickness in this work:

- Optical method
- Gravimetric method

A. Optical method:

In the measurement of thin films, optical methods are the favorite since they precise, non-destructive and need little to no sample preparation. There are two most used optical measurement types and they are: Spectral reflectance and Ellipsometry.

Spectral reflectance refers to the measure of the amount of light reflected from a thin film across a number of wavelengths, with the incident ray normal (perpendicular) to the sample surface. Ellipsometry measurements and that of spectral reflectance are of two different polarization and it measures at non-normal incidence. Spectral reflectance is most used optical measurement method than ellipsometry because of its low cost of operation but it has its flaw which is it restriction to measuring of less complex structure. The light absorption coefficient of the optical based technique is given by:

$$T = (1 - R)^2 \exp(-\alpha t) \qquad (2.10)$$

Where;

t = layer of thickness

R = reflectance

Taking the natural logarithm on both sides of equation (2.18) becomes;

$$\boldsymbol{t = In\ [(1 - R)^2 / T] / \alpha} \qquad (2.11)$$

B. Gravimetric method

The gravimetric method is given by:

$$Density = \frac{mass}{volume}$$

$$\rho = \frac{\mathrm{m_{2} - m_{1}}}{\mathrm{2At}} = \frac{\mathrm{m}}{\mathrm{2lbt}} \qquad (2.12)$$

where $t = \frac{m}{2lbt}$

t = film thickness

m = $m_2 - m_1$ is the mass of thin film being deposited, m_2 and m_1 are the masses of the glass slides after and before deposition.

A = Area of the film on a rectangular glass substrate with dimensions of l and b as length and breadth respectively.

2.5.2 MEASUREMENT OF THIN FILM OPTICAL PROPERTIES

The Ellipsometry technique is a technique that has been used for centuries to determine the thickness and optical properties of thin films and multilayer thin-films stacks. This technique involves measuring and interpreting the change of polarization state that occurs when a polarized light beam is reflected at normal incidence from a thin film surface. Since this technique does not depend on interference effects, thin film thickness determination are not limited to wavelength of light.

2.6 APPLICATIONS OF THIN FILMS

Thin film technology has historically been used in a wide range of applications from decorative purposes in its early stage, evolving for optical purposes latter on, and an endless range of applications supported by the rapid development of electrical power, etc. Some common applications include:

1. Optics and Photonics: Thin films are employed in anti-reflective coatings, mirrors, optical filters, and photochromic films.
2. Electronics and Semiconductors: Thin films are used in integrated circuits, transistors, diodes, memory devices, and display technologies.
3. Energy: Thin films are utilized in solar cells, batteries, fuel cells, and thermoelectric devices.
4. Surface Engineering: Thin films are employed in protective coatings, decorative coatings, .
5. Sensors and Actuators: Thin films are used in gas sensors, biosensors, and piezoelectric films.

6. Medical Applications: Thin films are employed in biocompatible coatings, drug delivery systems, and antimicrobial coatings.
7. Aerospace and Defense: Thin films are utilized in thermal barrier coatings, stealth technologies, and optical sensors.
8. Data Storage: Thin films are used in magnetic thin films and optical discs.

CHAPTER THREE

3.0 EXPERIMENTAL WORK AND MEASUREMENT

3.1 PREPATION OF GLASSES

Five samples of glass slide about 75 by 26mm and about 1mm thick were prepared by degreasing them in conc. hydrochloric acid. After the three days of degreasing, the slides were removed and dipped in distilled water.

Fig 3.1 Degreased and uncoated glass slides left to air dry

3.2 PREPARATION OF SOLUTE REAGENT SOLUTION

Fig 3.2 Preparation of the solute reagent used in the deposition

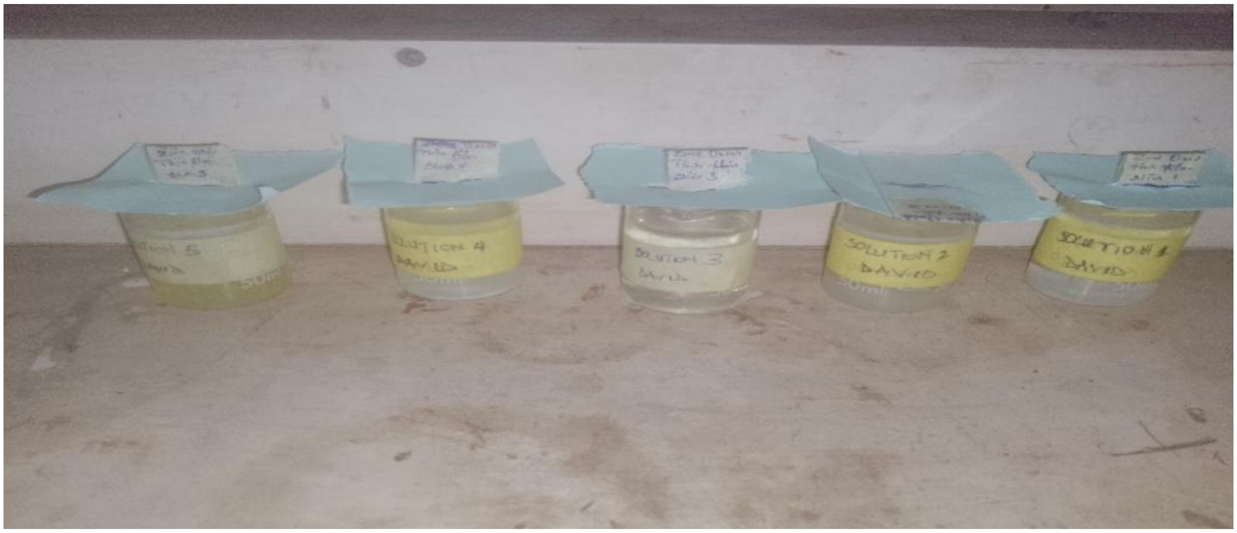

Fig 3.3: Deposition of Tin (II) Oxide SnO thin film in deposition bath concentration of 0.12 molarity at different deposition times at room temperature.

The following equation was used to calculate the mass of each solute reagent

$$M = \frac{M\ x\ W\ x\ Vol}{1000}$$

Where;

M = molar concentration

W = Molecular weight of chemical reagent

V = Volume of distilled water required for the solution

m = mass

3.2.1 PREPARATION OF TIN (II) OXIDE SOLUTION

In this experiment, the total mass of tin (ll) oxide was prepared at once to prevent inconvenience in preparing the tin (ll) oxide solution at separate times. In the case of error, extra volume of tin (ll) oxide was also prepared in sufficient amounts. The total mass of tin (ll) oxide prepared was calculated thus;

$$\boldsymbol{m = \frac{0.5\ x\ 225.63\ x\ 100}{1000} = 11.28g}$$

On an electronic balance, 11.28g of tin (ll) oxide was weighed using a clean and dry beaker. The tin (ll) oxide was dissolved in the measured amount of distilled water for dissolution.

3.2.2 PREPARATION OF SODIUM HYDROXIDE (NaOH) SOLUTION

In the preparation of sodium hydroxide, the same technique applied above is used

The same method was carried out in the preparation of 35ml of sodium hydroxide;

$$\boldsymbol{m = \frac{5\ x\ 39.997\ x\ 85}{1000} = 16.99g}$$

The mass of sodium hydroxide (16.99g) is weighed by using a measuring beaker and then dissolved in a clean flat bottom flask with distilled water, left overnight to ensure dissolution.

3.2.3 PREPARATION OF TIN (II) CHLORIDE-2-WATER

The total mass of tin (ii) chloride-2-water needed for this experiment was also prepared at once to prevent inconvenience in preparing the Tin (Ii) Chloride-2-Water solution at separate times. Additional volume of Tin (Ii) Chloride-2-Water was also prepared to ensure enough amount in case of error. The total mass of Tin (Ii) Chloride-2-Water was calculated by the following process

$$\boldsymbol{m} = \frac{\mathbf{5}\ \boldsymbol{x}\ \mathbf{136.286}\ \boldsymbol{x}\ \mathbf{75}}{\mathbf{1000}} = \mathbf{5.11}\boldsymbol{g}$$

3.3 PREPARATION OF SOLVENT REAGENTS SOLUTION

For the preparation of the solvent reagent, the volume of the solvent for a given molarity M is calculated using the following equation;

$$\boldsymbol{V} = \frac{\boldsymbol{M}\ \boldsymbol{x}\ \boldsymbol{Wt}\ \boldsymbol{x}\ \mathbf{100}}{\boldsymbol{d}.\boldsymbol{p}}\ \boldsymbol{x}\ \frac{\boldsymbol{Vt}}{\mathbf{1000}}$$

Where:

M = Molarity required

V = Total volume of ammonia solution

Wt = Molecular mass

Vt = Total volume required

d = Density and specific gravity

P = Percentage array

$$V = \frac{10\ x\ 17.031\ x\ 100}{0.88\ x\ 33}\ x\ \frac{35}{1000} = 20.53g$$

Volume of distilled water was obtained using:

$V_T = V_{H2O} + V_{NH3}$

$V_{H2O} = V_T - V_{NH3}$

$V_{H2O} = 35 – 20.53 = 14.47ml$

3.4 PREPARATION OF DEPOSITION BATH SOLUTION

Five (5) glass beakers of 50ml volumes each were used to carry out the deposition bath process. Reagents used for the deposition of tin (ll) oxide thin films were different volumes of 0.5M $SnCl_2.2H_20$, 10M of NH_3, used as a complexing agent, and 3M of NaOH solutions. Different volumes of distilled water were added to each beaker to increase the volume to the required volume(50ml). The equation below was used to calculate the accurate amount of molarity of tin (ll) oxide.

$M_1V_1 = M_2V_2$

Where;

M =Molarity

V = Volume

This was calculated as to achieve the right amount of molar concentration in each beaker as shown in fig 3.

Glass slide (No)	Deposition time (hrs)	Volume of 0.5M $SnCl_2.2H_20$ V ± $0.1cm^3$	Volume of 10M NH_3 V ± $0.1cm^3$	Volume of 5M NaOH solution V ± $0.1cm^3$	Volume of distilled water (H_2O) V ± $0.1cm^3$	Volume of Total solution V ± $0.1cm^3$	Molarity of $SnCl_2.2H_20$ In solution
1	12.0	12.0	5.0	14.0	19.0	50.0	0.12
2	18.0	12.0	5.0	14.0	19.0	50.0	0.12
3	24.0	12.0	5.0	14.0	19.0	50.0	0.12
4	30.0	12.0	5.0	14.0	19.0	50.0	0.12
5	36.0	12.0	5.0	14.0	19.0	50.0	0.12

Table 3.1 Chemical bath constituents for deposition of Tin (II) oxide (SnO) thin film at 0.12 molarity and room temperature for different deposition times.

3.5 THIN FILM DEPOSITION

A glass slide was suspended vertically in each of the bath solutions, and with the aid of a hard paper for covering the top of the beaker to prevent the slide from having contact with the bottom or sides of the beaker for deposition times of 12, 18, 24, 30 and 36hrs at 0.12 molarity.

Subsequently, the glass slide coated in SnO was then removed, rinsed with distilled water, and hanged in open air at room temperature. The thin film derived after the deposition was adherent and was transparent like in appearance.

3.6 MEASUREMENT

3.6.1 OPTICAL AND SOLID STATE DETERMINATION

The optical properties that were calculated in this experiment includes the absorbance (A), transmittance (T), reflectance (R), and absorbing power (a) and refractive index (n). The solid state measurements performed on the slides were the energy bandgap (Eg), and film thickness (t).

The measurement of the spectral absorbance was evaluated in the laboratory of the Biochemistry Department at the University of Benin, Benin City, Nigeria. To determine the absorbance of the films in the ultraviolet (UV), visible (VIS), an near infrared regions of the electromagnetic spectrum, a T80+ UV/VIS Spectrophotometer was used. The results of the spectral absorbance was read directly from the spectrophotometer while other properties such as transmittance, reflectance, refractive index, absorbing power, etc. were calculated from the absorbance spectral

The result of the spectral transmittance was obtained using Eqn(2.3), the spectral reflectance was obtained using Eqn(2.4), absorbing power was obtained from Eqn(2.6b), and the bangap of thin films deposited were calculated using Eqn(2.9e). The bandgap was further determined by the extension of linear plots of absorbing power (α^2) against photon energy (hv). Using Eqn(2.8d) the refractive index of the thin films was calculated. By optical method using Eqn(2.11) the film thickness (t) was obtained for films with absorbance A ≥ 0.1.

Fig 3.4:T80+ UV/VIS Double beam spectrophotometer

CHAPTER FOUR

4.0 EXPERIMENTAL RESULTS

TABLE 4.1: Spectral absorbance (A), transmittance (T), and absorbing power (α) of tin (ll) oxide thin films deposited on glass slides at 0.12M bath concentration at room temperature for 12hrs.

λ(nm)	A	T	R	$\alpha x10^{6}$ m^{-1}	hv	$\alpha^{2}x10^{10}$ m^{-2}
202	0.591	0.256	0.665	1.362	6.143	18.55
206	0.633	0.232	0.602	1.461	6.024	21.35
208	0.665	0.212	0.547	1.551	5.966	24.06
210	0.622	0.238	0.616	1.435	5.909	20.59
215	0.670	0.213	0.543	1.546	5.772	23.90
222	0.625	0.237	0.612	1.439	5.590	20.71
225	0.568	0.270	0.702	1.309	5.515	17.13
227	0.541	0.287	0.746	1.248	5.466	15.58
230	0.642	0.228	0.586	1.478	5.395	21.84
234	0.578	0.264	0.686	1.331	5.303	17.72
240	0.538	0.289	0.751	1.241	5.170	15.40
243	0.555	0.278	0.723	1.280	5.106	16.38
249	0.584	0.260	0.676	1.347	4.983	18.14
251	0.568	0.270	0.702	1.309	4.944	17.13
256	0.567	0.271	0.704	1.305	4.847	17.03
259	0.718	0.191	0.473	1.655	4.791	27.39
266	0.597	0.252	0.655	1.378	4.665	18.99

270	0.580	0.263	0.683	1.335	4.596	17.82
274	0.686	0.206	0.520	1.579	4.529	24.93
278	0.917	0.121	0.204	2.111	4.464	44.56
280	0.982	0.104	-0.086	2.263	4.432	51.21
285	1.743	0.018	-0.725	4.017	4.354	161.36
290	5.000	0.00001	-4	11.512	4.279	1325.26
300	0.357	0.439	0.204	0.823	4.136	6.77
306	5.000	0.00001	-4	11.512	4.055	1325.26
360	0.080	0.831	0.089	0.185	3.447	0.34
351	0.069	0.853	0.078	0.158	3.536	0.25
367	0.099	0.796	0.105	0.228	3.381	0.52

TABLE 4.2: Spectral absorbance (A), transmittance (T), and absorbing power (α) of tin (ll) oxide thin films deposited on glass slides at 0.12M bath concentration at room temperature for 18hrs.

λ(nm)	A	T	R	$\alpha x10^6$ m^{-1}	hv	α^2x10^{10} m^{-2}
202	0.576	0.265	0.159	1.328	6.144	17.64
206	0.584	0.260	0.156	1.347	6.024	18.15
208	0.575	0.266	0.159	1.324	5.966	17.54
210	0.611	0.244	0.145	1.411	5.910	19.90
213	0.565	0.272	0.163	1.302	5.826	16.95
216	0.497	0.318	0.185	1.146	5.745	13.13
219	0.546	0.284	0.17	1.259	5.667	15.85
222	0.473	0.336	0.191	1.091	5.590	11.90
224	0.535	0.291	0.174	1.234	5.540	15.24
229	0.508	0.310	0.182	1.171	5.419	13.72
236	0.506	0.311	0.183	1.168	5.258	13.64
241	0.456	0.349	0.195	1.053	5.149	11.08
243	0.526	0.297	0.177	1.214	5.107	14.74
247	0.521	0.301	0.178	1.201	5.024	14.42
251	0.537	0.290	0.173	1.238	4.944	15.32
254	0.539	0.289	0.172	1.241	4.886	15.41
257	0.594	0.254	0.152	1.370	4.829	18.78
259	0.549	0.282	0.169	1.266	4.792	16.02
263	0.499	0.316	0.185	1.152	4.719	13.27
270	0.632	0.233	0.135	1.457	4.596	21.22
273	0.606	0.247	0.147	1.398	4.546	19.55

275	0.632	0.233	0.135	1.457	4.513	21.22
277	0.664	0.216	0.12	1.532	4.480	23.48
280	0.823	0.150	0.027	1.897	4.432	35.99
283	0.891	0.128	-0.019	2.056	4.385	42.26
286	0.739	0.1821	0.0789	1.703	4.339	29.01
288	0.847	0.142	0.011	1.952	4.309	38.10
293	5.000	0.0001	-4	11.5129	4.235	1325.475
298	0.333	0.464	0.203	0.768	4.164	5.90
307	5.000	0.0001	-4	11.5129	4.042	1325.475
337	0.086	0.820	0.094	0.198	3.682	0.39
359	0.094	0.805	0.101	0.217	3.457	0.47
367	0.127	0.746	0.127	0.293	3.381	0.86

TABLE 4.3: Spectral absorbance (A), transmittance (T), and absorbing power (α) of tin (ll) oxide thin films deposited on glass slides at 0.12 M bath concentration at room temperature for 24hrs.

λ(nm)	A	T	R	$\alpha \times 10^6$ m^{-1}	hv	$\alpha^2 \times 10^{10}$ m^{-2}
202	0.539	0.289	0.172	1.241	6.144	15.41
207	0.534	0.292	0.174	1.231	5.995	15.15
211	0.507	0.311	0.182	1.168	5.882	13.64
217	0.546	0.284	0.17	1.259	5.719	15.85
226	0.533	0.293	0.174	1.228	5.491	15.07
228	0.461	0.345	0.194	1.064	5.443	11.33
231	0.519	0.302	0.179	1.197	5.372	14.34
235	0.472	0.337	0.191	1.088	5.281	11.83
238	0.542	0.287	0.171	1.248	5.214	15.58
240	0.546	0.284	0.170	1.259	5.171	15.85
243	0.521	0.301	0.178	1.201	5.107	14.42
246	0.587	0.258	0.155	1.355	5.045	18.35
248	0.508	0.310	0.182	1.171	5.004	13.72
251	0.496	0.319	0.185	1.143	4.944	13.05
258	0.543	0.286	0.171	1.252	4.810	15.67
261	0.594	0.254	0.152	1.370	4.755	18.78
263	0.529	0.295	0.176	1.221	4.719	14.90
268	0.658	0.219	0.123	1.519	4.631	23.06
271	0.646	0.225	0.129	1.492	4.579	22.25
275	0.537	0.290	0.173	1.238	4.513	15.32
277	0.661	0.218	0.121	1.523	4.480	23.20

280	0.759	0.174	0.067	1.749	4.432	30.58
282	0.873	0.133	-0.006	2.017	4.401	40.70
288	0.782	0.165	0.053	1.802	4.309	32.47
290	0.804	0.157	0.039	1.852	4.279	34.28
294	5.000	0.00001	-4	11.5129	4.221	1325.475
300	0.318	0.480	0.202	0.734	4.137	5.39
308	5.000	0.00001	-4	11.5129	4.029	1325.475
323	0.083	0.826	0.091	0.191	3.842	0.37
341	0.105	0.785	0.11	0.242	3.639	0.59
362	0.095	0.803	0.102	0.219	3.428	0.48
367	0.122	0.755	0.123	0.281	3.381	0.79

TABLE 4.4: Spectral absorbance (A), transmittance (T), and absorbing power (α) of tin (ll) oxide thin films deposited on glass slides at 0.12M bath concentration at room temperature for 30hrs.

λ(nm)	A	T	R	$\alpha x10^6$ m^{-1}	hv	$\alpha^2 x10^{10}$ m^{-2}
203	0.460	0.347	0.193	1.0592	6.113	11.22
206	0.524	0.299	0.177	1.2066	6.024	14.56
208	0.402	0.396	0.202	0.9256	5.966	8.57
212	0.500	0.316	0.184	1.1513	5.854	13.26
218	0.446	0.358	0.196	1.0270	5.693	10.55
222	0.479	0.332	0.189	1.1029	5.590	12.17
224	0.449	0.356	0.195	1.0339	5.540	10.69
226	0.486	0.327	0.187	1.1191	5.491	12.52
228	0.463	0.344	0.193	1.0661	5.443	11.37
230	0.492	0.322	0.186	1.1329	5.396	12.83
236	0.385	0.412	0.203	0.8865	5.258	7.86
240	0.434	0.368	0.198	0.9993	5.171	9.99
246	0.519	0.303	0.178	1.1950	5.045	14.28
250	0.444	0.360	0.196	1.0223	4.964	10.45
252	0.444	0.360	0.196	1.0223	4.925	10.45
256	0.491	0.323	0.186	1.1306	4.848	12.78
258	0.495	0.320	0.185	1.1398	4.810	12.99
261	0.526	0.298	0.176	1.2112	4.755	14.67
265	0.477	0.333	0.190	1.0983	4.683	12.06
269	0.471	0.338	0.191	1.0845	4.613	11.76
271	0.503	0.314	0.183	1.1582	4.579	13.41

273	0.552	0.281	0.167	1.2710	4.546	16.16
275	0.501	0.316	0.183	1.1536	4.513	13.31
277	0.518	0.303	0.179	1.1927	4.480	14.23
280	0.546	0.284	0.170	1.2572	4.432	15.81
283	0.541	0.288	0.171	1.2457	4.385	15.52
288	0.764	0.172	0.064	1.7592	4.309	30.95
291	0.642	0.228	0.130	1.4783	4.265	21.85
293	0.860	0.138	0.002	1.9802	4.235	39.21
295	5.000	0.00001	-4.000	11.5129	4.207	1325.48
300	0.321	0.478	0.201	0.7391	4.137	5.46
303	0.357	0.440	0.203	0.8220	4.096	6.76
308	5.000	0.00001	-4.000	11.5129	4.029	1325.48
326	0.165	0.684	0.151	0.3799	3.807	1.44
333	0.177	0.665	0.158	0.4076	3.727	1.66
362	0.163	0.687	0.150	0.3753	3.428	1.41
367	0.185	0.653	0.162	0.4260	3.381	1.82
505	0.128	0.745	0.127	0.2947	2.457	0.87

TABLE 4.5: Spectral absorbance (A), transmittance (T), and absorbing power (α) of tin (ll) oxide thin films deposited on glass slides at 0.12 M bath concentration at room temperature for 36hrs.

λ(nm)	A	T	R	$\alpha x10^{6}$ m^{-1}	hv	$\alpha^{2}x10^{10}$ m^{-2}
203	0.631	0.233	0.302	1.456	6.113	21.20
205	0.567	0.271	0.704	1.305	6.053	17.03
213	0.617	0.241	0.624	1.422	5.826	20.22
216	0.655	0.221	0.566	1.509	5.745	22.77
221	0.627	0.236	0.609	1.443	5.615	20.82
225	0.622	0.238	0.616	1.435	5.515	20.59
230	0.537	0.290	0.753	1.237	5.395	15.30
234	0.640	0.229	0.589	1.474	5.303	21.73
239	0.549	0.282	0.733	1.265	5.192	16.00
241	0.564	0.273	0.709	1.298	5.149	16.85
243	0.593	0.255	0.662	1.366	5.106	18.66
245	0.611	0.244	0.634	1.410	5.065	19.88
248	0.671	0.213	0.542	1.546	5.004	23.90
251	0.573	0.267	0.694	1.320	4.944	17.42
253	0.543	0.286	0.743	1.251	4.905	15.65
261	0.614	0.243	0.143	1.414	4.754	19.99
263	0.551	0.281	0.730	1.269	4.718	16.10
267	0.655	0.221	0.566	1.509	4.647	22.77
269	0.702	0.198	0.496	1.619	4.613	26.21

271	0.708	0.196	0.488	1.629	4.579	26.54
274	0.722	0.189	0.467	1.666	4.529	27.76
278	0.830	0.147	0.317	1.917	4.464	36.75
280	0.708	0.195	0.487	1.634	4.432	26.70
284	1.029	0.093	0.064	2.375	4.369	56.41
289	0.827	0.148	0.321	1.910	4.294	36.48
291	0.939	0.115	0.176	2.162	4.264	46.74
294	5.000	0.00001	-4.00001	11.51	4.221	1324.80
299	0.368	0.428	1.060	0.848	4.150	7.19
301	0.370	0.426	1.056	0.853	4.122	7.28
308	5.000	0.00001	-4.00001	11.51	4.029	1324.80
333	0.183	0.656	1.453	0.421	3.726	1.77
356	0.170	0.676	1.506	0.391	3.485	1.53
367	0.193	0.641	1.448	0.444	3.381	1.97

Table 4.6: Average optical properties of tin (ii) oxide (sn0) thin film deposited by improved solution growth technique (sgt) in bath solution at 0.12 molarity for different deposition times at room temperature.

Average Optical Properties	Deposition Temperature (℃)	Deposition Time (Hours)				
		12	18	24	30	36
λ(nm)	27.0	261	260.3	267	272	264.4
A	27.0	0.658	0.594	0.562	0.474	0.551
T	27.0	0.222	0.254	0.275	0.336	0.281
R	27.0	0.564	0.152	0.164	0.191	0.730
$\alpha^2 \times 10^6\ m^{-2}$	27.0	2.121	1.862	1.830	1.594	1.999
n	27.0	7.032	2.278	2.361	2.553	12.736

Table 4.6.1: Average solid state properties of tin (ii) oxide (sn0) thin film deposited by improved solution growth technique (sgt) in bath solution at 0.12 molarity for different deposition times at room temperature.

Average solid state properties	Deposition Temperature (℃)	Deposition Time (Hours)				
		12	18	24	30	36
Film thickness (t)	27.0	-0.073	0.558	0.509	0.418	-0.674
Bandgap Eg (eV)	27.0	4.754	4.767	4.647	4.562	4.693

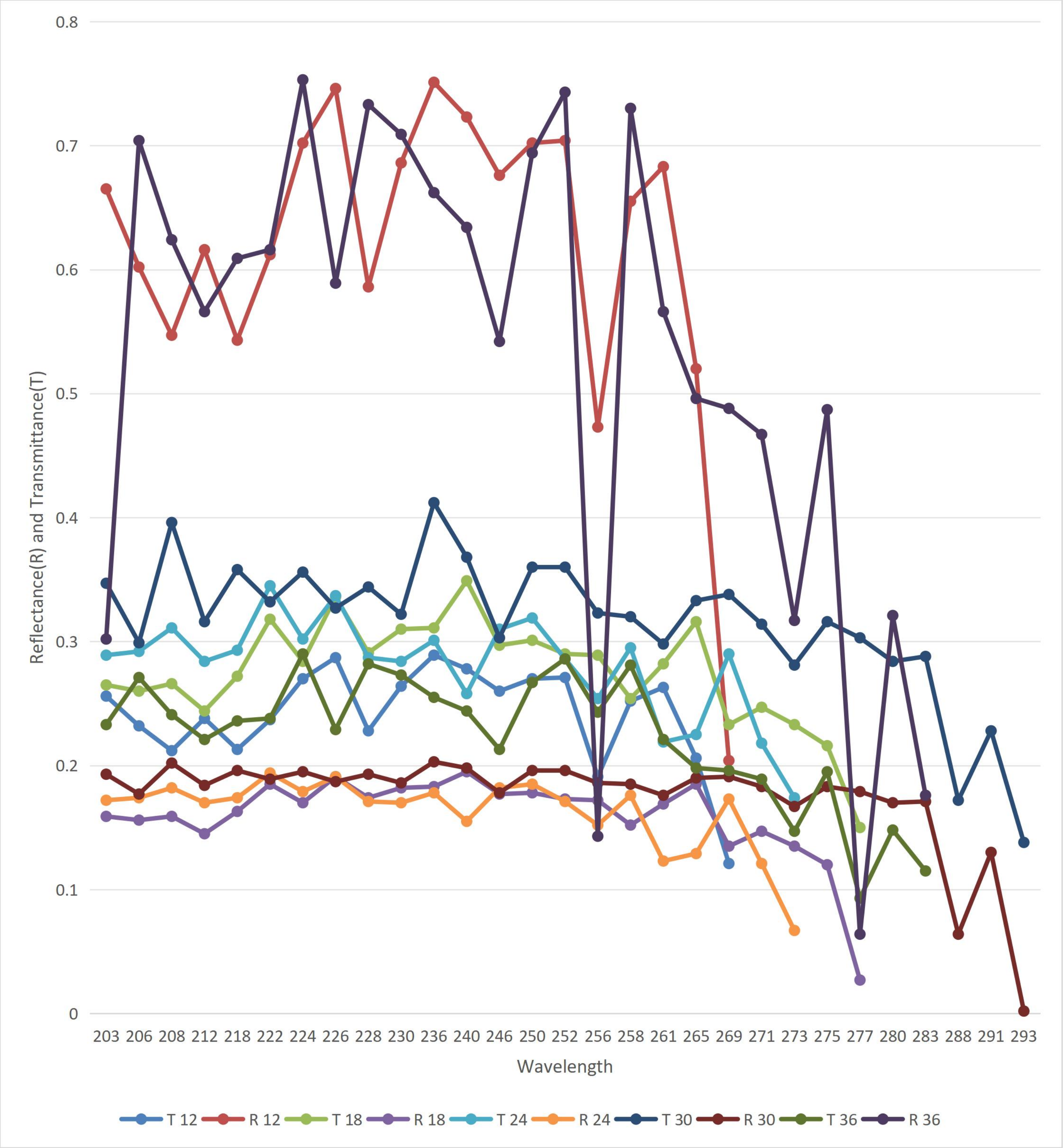

Fig 4.1: Plot of Transmittance - Reflectance spectra of Tin (ll) oxide thin films deposited on glass by solution growth technique in a deposition bath of same concentration at different deposition times at room temperature.

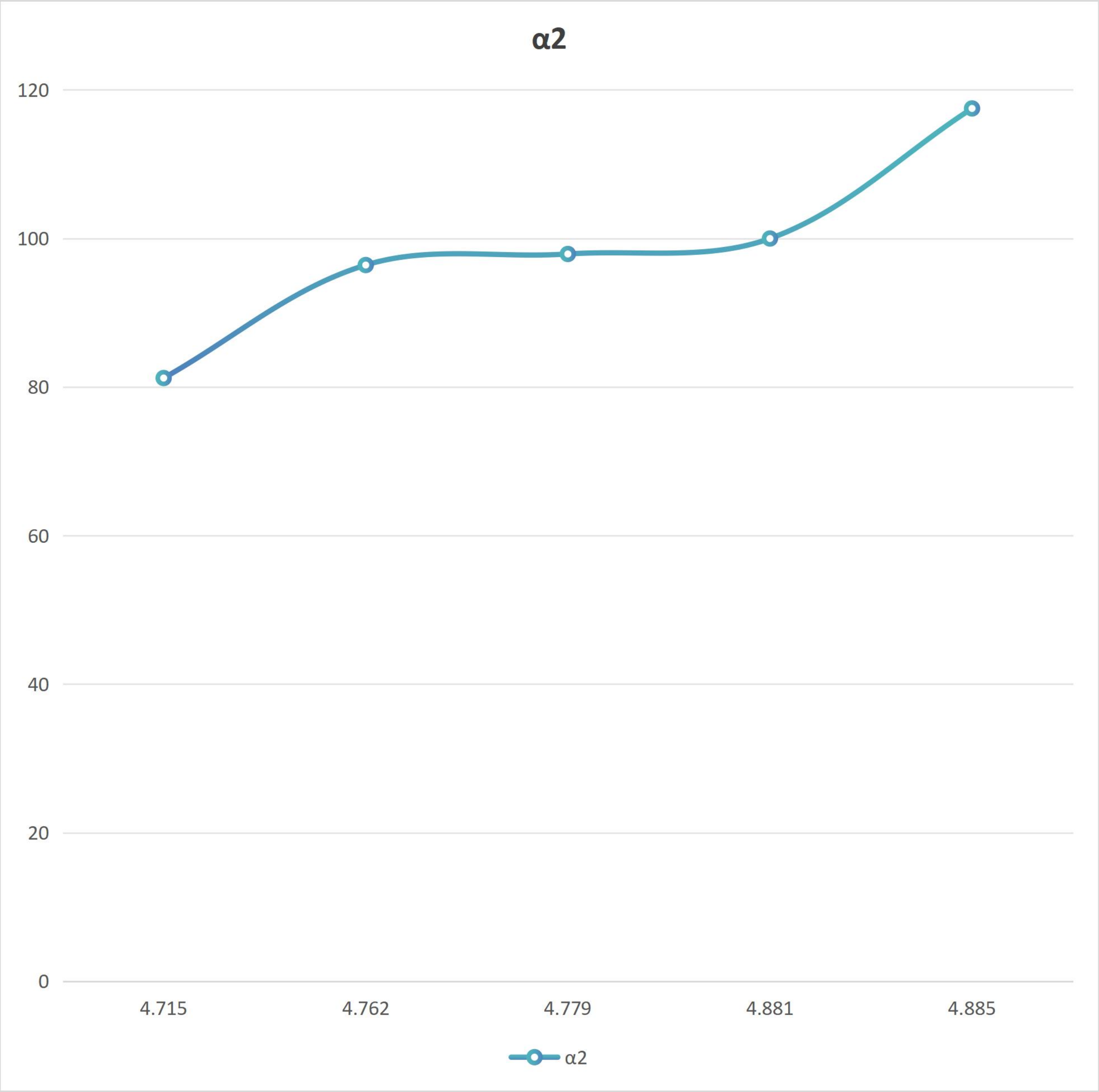

Fig 4.2: Plot of the average values of the square of absorption coefficient against photon energy for tin (II) oxide thin films deposited on glass by solution growth technique at same molar concentration for different deposition times at room temperature.

CHAPTER FIVE

5.0 DISCUSSION, RECOMMENDATION AND CONCLUSION

5.1 DISCUSSION

The absorbance, transmittance and reflectance spectra of the tin(ii)oxide thin films deposited at varying time intervals and at 0.12 molar concentration, at room temperature, are presented in Table 4.1. The results indicate that the SnO thin films exhibit high transmittance (T) and low reflectance (R). The transmittance of the films increases with wavelength for a fixed deposition time but decreases with increasing deposition time at a constant bath concentration. Conversely, absorbance (A) decreases with increasing wavelength but increases with deposition time. A decrease in absorbance (A) corresponds to a decrease in reflectance (R) and an increase in transmittance (T). The transmittance (T) and reflectance (R) of the films are dependent on absorbance (A) within the 202-505 nm wavelength range.

The maximum transmittance of 0.853 corresponds to the lowest absorbance of 0.069 at 351nm for thin films created after 24 hour deposition time. The minimal transmittance of 0.00001which is equivalent to an absorbance of 5 is the same for all the thin films deposited at different deposition times. The thin film created at a deposition time of 36 hours had the highest reflectance of 1.506, which is equivalent to an absorbance of 0.17 at a wavelength of 356nm

It is shown that high transmittance and low reflectance properties of the tin (ll) oxide thin films in the ultra violet visible and near infrared regions of the electromagnetic spectrum could be used to produce anti reflection coatings for transparent covers of solar thermal devices to improve their efficiency, eye glass coatings to reduce reflection and improve the transmittance of light and thermal control window coatings for cold climates when coated on glass to reduce reflection loss and enhance transmission of light into buildings (Ilenikhena et al.2005). It can be also observed from Table 4.1 that as the deposition time of the film increases the transmittance (T) reduces, while the absorbance (A) and reflectance (R) increases.

The following are some observations gotten from this work;

- The maximum transmittance (T), lowest reflectance (R), and lowest absorbance (A) are found in the film produced at a a deposition time of 24 hours.
- The minimum transmittance (T), highest reflectance (R), and highest absorbance (A) are the same for all the films produced at different deposition times.
- The absorbing power magnitude $\alpha \times 10^6 \, m^{-1}$, which depends on absorbance (A), is between $10^4 - 10^5 \, cm^{-1}$ for semiconductor thin films ideal for the manufacture of thin film solar cells (Chopra, et al, 1983).
- The refractive index (n) values of the deposited thin films corresponds with findings cited by Gray (1972), Ballard et al. (1972), Malitson (1964), Steinmetz et al. (1967) and Duncanson and Stevenson. (1958)

Absorption coefficient method was applied to obtain the band gap of the SnO films produced. Values of band gap (Eg) vary from 4.754 - 4.693eV, the film thickness ranges from -0.073 - (-0.063).

5.2 POSSIBLE APPLICATIONS OF THE DEPOSITED TIN (II) OXIDE THIN FILMS

The optical characteristics of the SnO thin films made under different deposition times exhibit high spectral transmittance (T) in the ultraviolet (UV), visible (VIS), and near infrared (NIR) regions of the electromagnetic spectrum, low reflectance in the UV, and a refractive index (n) less than 1.8

These deposited thin films can be used in:

1. Electronic industries as transparent contacts or electrodes for photoactivated and photoelectrochemical cells (P.E.C)
2. Architecture sector as heat mirror coatings to lower thermal losses from heated interior to exterior in temperate zones with serious winters.
3. Solar thermal devices as antirefloection (AR) coatings on transparent covers to improve their efficiency.
4. Architectural industries as thermal control window coatings for cold seasons to reduce reflection loss.

The various deposition times have the same maximum absorbance in the ultraviolet (UV), visible (VIS), and near-infrared regions (NIR), the same lowest transmittance and the same maximum reflectance, as well as a refractive index greater than 1.8. They can also be applied in the:

- Optical industry for the manufacture of eye glass coatings as a shield of the skin around the eye from ultraviolet radiation.
- Electronic industry for the manufacture of thin film transistors.
- Car industry for the manufacture of anti-dazzling coatings for windscreens to reduce the effect of light at night.

5.3 RECOMMENDATIONS

Tin (ll) oxide thin films can be created with:

- Same molar concentration at room temperature for different deposition times from 12 to 36hrs.
- Same molar concentration at higher temperature for 4 hours.
- Different molar concentrations for 24 hours at room temperature.

5.4 CONCLUSION

Thin films of tin(ii)oxide (SnO) were successfully deposited on glass slides at room temperature using an improved solution growth technique (SGT) with varying deposition times (12, 18, 24, 30, and 36 hours). The absorbance properties of the films were analyzed using a T80+ UV/VIS Double beam spectrophotometer at different wavelengths, while other properties were calculated based on theoretical models. The results show a range of optical and solid-state properties, including absorbance, transmittance, reflectance, absorbing power, refractive index, film thickness, and bandgap energy. These films have potential applications in various fields, including construction, solar cells, and anti-dazzling coatings.

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