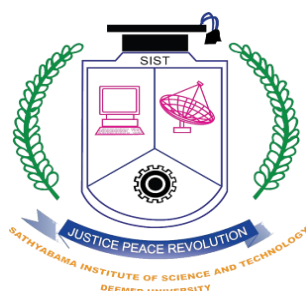


PHYSICAL INTERPRETATION OF PURE & ALUMINUM DOPED TIN OXIDE THIN FILMS FOR SOLAR CELL APPLICATIONS

Submitted in partial fulfilment of the requirements for the award of
Master of Science degree in Physics

By

P. TAMILARASAN
(41590023)



DEPARTMENT OF PHYSICS
SCHOOL OF SCIENCE AND HUMANITIES

SATHYABAMA

**INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)**

Accredited with “A” grade by NAAC | 12B Status by UGC

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May 2023



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BONAFIDE CERTIFICATE

This is to certify that this Project Report is the bonafide work of M. SUNDARESAN (41590022) who carried out the project entitled "PHYSICAL INTERPRETATION OF PURE & ALUMINIUM DOPED TIN OXIDE THIN FILMS FOR SOLAR CELL APPLICATIONS" under my supervision from November 2022 to May 2023.

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Submitted for Viva voce Examination held on 9.5.2023 2023

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DECLARATION

I P. TAMILARASAN, hereby declare that the Project Report entitled PHYSICAL INTERPRETATION OF PURE & ALUMINIUM DOPED TIN OXIDE THIN FILMS FOR SOLAR CELL APPLICATIONS done by me under the guidance of Dr. C. Rameshkumar (Internal), Department of Physics, Sathyabama Institute of Science and Technology, Chennai is submitted in partial fulfilment of the requirements for the award of Master of Science Degree in Physics.

DATE: 09-05-2023

PLACE: CHENNAI



SIGNATURE OF THE CANDIDATE

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Abstract

Research and development in thin film technology has accelerated over the last two decades due to its widespread application in almost all fields of science and technology. Thin film technology plays an important role in high-tech industry. Thin film technology was developed primarily for the needs of the integrated circuit industry. As far as solar cells are concerned, transparent semiconductor materials such as SnO_2 , InO_3 , and ZnO are well suited for important applications as highly resistive transparent layers in thin-film solar cells with high conversion efficiency. In this project, we wanted to study the electrical transport and optical mechanisms of SnO_2 thin films using the dip coating technique. The materials used are $\text{SnCl}_2 \cdot \text{H}_2\text{O}$ as precursor, $\text{C}_2\text{H}_5\text{OH}$ as solvent and $\text{Al}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$ as dopant. SnO_2 thin films are obtained by applying a SnCl_2 + ethanol solution (prepared as a homogeneous solution using a hot magnetic stirrer) onto a glass substrate using a programmable dip coater and annealing at 400°C for 1h. The presence of tin oxide was confirmed by XRD techniques. The thickness of doped and undoped SnO_2 thin films, the electrical and optical properties of the thin films were investigated.

CHAPTER 1

INTRODUCTION

1.1 Thin Film:

The ability of the materials science and engineering community to design new materials with extraordinary combinations of chemical, physical and mechanical properties have transformed modern society. Technology advances more and more and the latest technology requires thin films for various applications. Thin-film technology is the basis for amazing developments in solid-state electronics. The usefulness of the optical properties of metallic films and the scientific curiosity about the behaviour of two-dimensional solids have fuelled tremendous interest in the study of thin film science and technology.

Thin-film research has developed many new research areas of solid-state physics and chemistry that depend, directly or indirectly, on phenomena specific to film thickness, shape, and structure. When looking at a film of matter, there are situations where two surfaces are very close together. They can therefore have a decisive influence on the internal physical properties of matter. Decreasing distances between surfaces and their interactions can give rise to entirely new phenomena. Here, the first dimension of materials is reduced to the order of a few atomic layers, creating an intermediate system between macroscopic and molecular systems, providing a way to study the microphysical properties of various processes. Thin films are particularly suitable for applications in microelectronics and integrated optics. However, the physical properties of the film, such as electrical resistance, do not differ significantly from those of the substrate. For thin films, the thickness limit is from tenths of a nanometre to several micrometres.

Thin film materials are a key component of continuous technological progress in the fields of optoelectronics, photonics, and magnetic devices. By processing the material into thin films, it can be easily integrated into various types of devices. When analysed in thin film form, the properties of materials vary greatly. Most functional materials tend to be applied in thin layers for specific electrical, magnetic, optical properties or wear resistance. Thin film technology takes advantage of the

fact that properties can be controlled, especially via the thickness parameter. Thin films are mainly formed by deposition by physical or chemical methods. Thin layers, both crystalline and amorphous, are of great importance in the high-tech era. Some of them are:

Microelectronic devices, magnetic thin films in recorders, magnetic sensors, gas sensors, A.R coatings, photoconductors, IR detectors, interference filters, solar cells, polarizers, temperature controllers in satellites, superconducting films, anti-corrosion, and decorative coatings.

1.2 Importance of Thin films:

Significant advances have been made in thin film technology to facilitate the rapid development of highly integrated miniature electronic circuits. In such devices, charge confinement relies heavily on interfaces between materials with different electronic properties. Moreover, the need for thin materials with very high quality, reproducible properties, and reliability has driven film growth technology by achieving a series of important achievements. Recently, advances in the physics of material structure based on quantum confinement of charge carriers continue to revolutionize the field. These systems bring new challenges to materials synthesis, characterization, and modelling.

The use of surface coatings to protect building materials in high temperature environments is another thin film technology of great commercial importance. For example, gas turbine engines use thin surface films of materials chosen for their chemical inertness, stability at high temperatures, and low thermal conductivity to increase engine efficiency and protect the useful life of constituent materials. greatly extend the Multilayer or sequentially graded coatings offer the potential for further advancement in this effort. The service life of parts subject to friction and contact can be greatly extended by using surfaces.

Surface coatings or treatments can significantly extend the life of components exposed to friction and contact wear. Technologies relying on the use of such thin films include internal combustion engines, artificial hip and knee implants, and computer hard drives for magnetic data storage.

Thin films are an integral part of many microelectromechanical systems intended to function as sensors and actuators. For example, a piezoelectric or piezoresistive thin film is deposited on a silicon film in response to pressure applied to its surface or acceleration of its support. Devices based on thin-film technology are used as microphones in hearing aids, blood pressure monitors during exercise, thin-film mirrors electronically placed on flexible supports in optical display systems, and probes to detect the ripeness of fruit.

1.3 Thin Film Technology:

Thin film technology plays an important role in high-tech industry. Thin film technology was developed primarily for the needs of the integrated circuit industry. Especially for the new generation of integrated circuits, the need to develop smaller and faster devices requires advanced materials. Fabrication of device thin films has been developed over the last 40 years. Thin layers as two-dimensional systems are of great importance for many practical problems. Their material cost is very low compared to their bulk counterparts and they perform the same function in surface treatment. Knowledge and insight into the properties, functions and new properties of thin layers can therefore be used to develop new techniques for future applications.

Thin-film technology is based on these three principles:

Manufacturing, Characterization, and Applications. Important applications of thin films include microelectronics, communications, optoelectronics and catalysis, all kinds of coatings, and strategies for energy generation and storage.

1.4 Thin Film Processing:

Thin film properties and versatility can be obtained by choosing an appropriate deposition technique. Thin film deposition can be broadly classified as either physical or chemical processes. The difference between physical and chemical thin film deposition methods depends on how the thin film material is deposited on the substrate. There are three types of thin film deposition techniques.

- Chemical vapor deposition technology
- Physical deposition techniques
- Sol-gel method

1.4.1 Chemical Deposition Technique:

Chemical deposition techniques use liquid precursors that chemically react with the substrate. When the thin film material passes through the liquid precursor, the chemical deposition approaches the substrate conformally without favouring any direction. A conformer is a heterogeneous interface with the body and has a constant thickness in the horizontal and vertical planes.

a) Chemical Vapour Deposition (CVD): CVD is a chemical process that uses gaseous precursors. The precursor gas is moved into the chamber along with the substrate. The chemical reaction between the substrate and precursor is continued at elevated temperature until the desired film thickness is reached.

b) Plasma Enhanced CVD: In PECVD, a plasma is formed within a reaction chamber to transform gaseous starting materials into reactive radicals, ions, neutral atoms, and molecules. These atomic and molecular fragments interact with the substrate and this chemical reaction forms a solid layer on the surface of the substrate. PECVD uses low temperatures (300-350 degrees Celsius) to deposit thin films, whereas CVD uses high temperatures (600-900 degrees Celsius) to form thin films.

c) Atomic Layer Deposition: Atomic layer deposition uses two or more gaseous precursors to react sequentially with a substrate. Thin films obtained by this method are conformal. The ALD process is divided into two half-reactions. These reactions include precursor deposition and evacuation of the reaction chamber. These occur sequentially and are repeated for each precursor. This chemical reaction takes place on the substrate to form the desired film thickness. ALD is a gradual process. It is therefore slower but can run at lower temperatures.

d) Chemical Solution Deposition: Sol-gel is a chemical solution deposition process in which the precursor solution for depositing the film is tightly controlled. The sol-gel process involves alkoxides where these polycondensation reactions take place, followed by hydrolysis of the alkoxy groups to initially yield a polymeric oxide network.

1.4.2 Physical Deposition Process:

Physical deposition techniques use mechanical or electromechanical methods to deposit thin films onto substrates. Materials deposited on a substrate depend on temperature, pressure, and other physical conditions. In these physical processes, particles follow straight-line paths from the target to the substrate, so the thin films formed are inherently directional.

a) Molecular Beam Epitaxy (MBE): MBE combines the advantages of physical and chemical processes for thin film deposition. First, the target material to be deposited is directly heated until it changes from solid to gaseous state. The gaseous element is then chemically reacted with the substrate to grow a thin film. In MBE, the target material is deposited in layers, but layer by layer. MBE is a slow method, but the purity of this method is very high.

b) Sputtering: Sputtering is a physical thin film deposition process in which atoms are ejected from a target material and come to rest on a substrate. The target material is kept cold. In this method, a plasma of inert gas such as argon is used as the target material. Therefore, inert gases do not cause unwanted chemical reactions. This is a quick and effective method to achieve the desired film thickness.

c) Pulsed Laser Deposition: It is an ablation process. A high-power pulse of laser light is focused onto the surface of a target material in a vacuum chamber. This leads to evaporation of the target material. Atoms removed from the target material are deposited on the substrate.

d) Cathodic Arc Deposition: Cathodic arc deposition is also known as arc PVD. This is a type of ion beam deposition in which an electric arc is generated that blows ions away from the target material being deposited (known as the cathode). This arc vaporizes the cathode target material. The evaporated target condenses on the substrate to form a thin film.

e) Thermal Evaporation Method: Starting materials to be deposited are evaporated under vacuum in a high-vacuum coating chamber using electron beams or resistive heating. The vacuum causes vapor particles to move directly to the substrate, where they condense back to a solid state to form a thin film.

f) Electro Hydrodynamic Deposition: Electrohydrodynamic deposition is also known as an electrospray deposition process. In this method, a liquid (a mixture of a suitable solvent such as methanol and nanoparticles to be deposited) flowing through a capillary nozzle is stressed by applying a high electric field while the substrate is held at ground potential. This voltage deposits fine droplets on the substrate. The substrate is heated to completely evaporate the solvent.

1.4.3 Sol-Gel Technique:

A sol is a dispersion of solid particles in a liquid where only Brownian motion keeps the particles suspended. Suspensions of particles with linear dimensions between 1 nm and 1 μm are called colloids and are formed by hydrolysis and polycondensation reactions of metal alkoxides such as oxides of Si and Ti. These Si and Ti oxides are called precursors. A precursor is a compound that participates in a chemical reaction to produce another compound. A number of organometallic precursors, including alkoxides, carboxylates, diketonates, and various organic salts, are used to form the initial metal complex solution, but from a commercial standpoint, alkoxides of most metals are synthesized. and is a convenient starting material in terms of availability and cost.

A gel describes a solid network containing a liquid component, with the liquid and solid dispersed. Gels are porous, three-dimensionally connected semi-solid networks that stably extend through liquid media and are limited by the size of the container. A gel is said to be colloidal when a solid network is created using colloidal sol particles. The liquid lies between the meshes of the solid network forming the gel, does not flow spontaneously, and is in thermodynamic equilibrium with the solid network.

The sol-gel process consists of four steps:

- a) Once the desired colloidal particles are dispersed in a liquid to form a sol.
- b) Deposition of the sol solution creates a coating on the substrate by spraying, dipping, or spinning. Particles in the sol polymerize upon removal of the constituents to form a continuous network-like gel.

c) A final heat treatment pyrolyzes any remaining organic or inorganic components to form an amorphous material that can be converted to crystalline by an annealing process.

Thin films of sol can be deposited using the following methods:

(i) Dip coating

(ii) Spin coating

(iii) Spray pyrolysis

Thin films are made by depositing precursor solutions on various substrates. Amorphous gel films are pyrolyzed at relatively low temperatures (300°C. to 700°C.) to form amorphous or crystalline oxides and subsequently annealed at relatively high temperatures to allow crystallization.

1.4.3.1 Dip Coating Technique

Dip-coating technology is a process in which the substrate to be coated is immersed in a coating sol to form a wet layer and then withdrawn at a well-defined withdrawal rate under controlled temperature and atmosphere. The dip coating technique is shown below. The atmosphere controls the evaporation of the solvent and triggers the gelation process leading to film formation. The resulting film must be densified by heat treatment, and the densification temperature depends on the composition.

1.4.3.2 Spin Coating Technique:

Spin-coating is currently the primary technique used to produce uniform thin films of photosensitive organic materials with thickness on the order of microns and nanometres. A pioneering analysis of this spin coating was performed by Emil et al. more than 50 years before him (1958) considered the propagation of a thin axisymmetric film of Newtonian fluid on a planar substrate rotating at constant angular velocity. Coating materials are often polymers and are applied in the form of solutions in which the solvent evaporates. Spin coating was first explored for coating paint and pitch. This process is widely used in the manufacture of integrated circuits, optical mirrors, colour television screens, and magnetic disks for data storage. Centrifugal force pushes the liquid radially outward. Viscous forces and

surface tension leave a thin residual film on the flat substrate. The film thins due to a combination of outward liquid flow and evaporation.

Spin coating has long been widely used in the semiconductor industry, but little theoretical research has begun. A precise theory of spin coating improves process design and control in a variety of applications. Decades of industrial production have demonstrated near-perfect control over the deposition of thin photoresist layers, the primary application of the spin-coating process.

1.4.3.3 Spray Pyrolysis Technique:

Spray pyrolysis is a processing technique being investigated for producing thin and thick films, ceramic coatings, and powders. Unlike many other deposition processes, spray pyrolysis is a very simple and relatively inexpensive processing method, offering a very straightforward technique for producing films of any composition. Spray pyrolysis does not require high quality substrates or chemicals. This process is used in dense film, porous film, and powder manufacturing. Spray pyrolysis has been used for decades in the glass industry and solar cell manufacturing. A typical spray pyrolysis system consists of a nebulizer, a precursor solution, a substrate heater, and a temperature controller.

Spray pyrolysis technology is commonly used:

Air blast (liquid is expressed in air vapor), ultrasonic (ultrasonic frequencies produce the short wavelengths necessary for atomization), and electrostatic (liquid is subjected to high electric field).

1.5 Application of Thin Films:

Although the study of thin film phenomena dates back more than a century, it is only in the last 40 years that they have come to full use in practical contexts. The need for ultra-miniaturization has made the use of thin and thick films virtually essential. Advances in computer technology have required very high-density storage technology, which has stimulated most of the research on the magnetic properties of thin films. Many thin film devices have been developed for an application, or perhaps more important market. In general, these devices arose from the study of

the physical properties of thin films. Thin film materials are used in semiconductor devices, wireless communications, telecommunications, integrated circuits, rectifiers, transistors, solar cells, light emitting diodes, photoconductors, liquid crystal displays, magneto-optical storage devices, audio and video systems, compact discs, electronic equipment, etc. used. Optical coatings, memory, multilayer capacitors, flat panel displays, intelligent windows, computer chips, magneto-optical discs, lithography, micro-electrochemical systems, multifunctional new coatings, and other new cutting technologies.

1.6 Recent Research on Thin Films:

Recently, a lot of research has been done on thin films. A thin film is a thin layer of material, typically only a few nanometres to a few microns thick. Thin films have a wide range of applications in various fields such as electronics, optoelectronics, energy, and medicine.

Recent research in the thin film field includes:

1. Flexible and transparent electronics:

Flexible and transparent electronics are becoming increasingly important, and thin films are a key component of these devices. Recent research has focused on developing thin films that can be easily deposited on flexible substrates such as plastics and retain their electrical properties when stretched or bent.

2. Solar cell:

Thin films are widely used in the production of solar cells that convert sunlight into electricity. Researchers are constantly working to improve the efficiency of solar cells, and thin films play an important role. Recent research has focused on developing new types of thin films that can be used to increase the efficiency of solar cells.

3. Nanotechnology:

Nanotechnology involves manipulation of materials at the atomic and molecular level. Thin films are commonly used in nanotechnology applications, and recent

research has focused on developing new types of thin films that can be used to create nanoscale structures with unique properties.

4. Medical applications:

Thin films are also used in medical applications such as drug delivery and tissue engineering. Recent research has focused on developing thin films that can be used to deliver drugs to specific areas of the body or to promote tissue regeneration. Overall, thin film research is ongoing and is likely to continue to advance rapidly as new applications are identified and new materials and techniques are developed.

1.7 Outline:

Research and development in thin film technology has increased rapidly over the past two decades due to its widespread application in almost all fields of science and technology. Thin film technology plays an important role in high-tech industry. Thin film technology was developed primarily for the needs of the integrated circuit industry. Knowing and determining the nature and new properties of thin films can be used to develop new techniques for future applications. Thin-film technology is based on his three principles:

1. Manufacturing

2. Characterization

3. Applications

As far as solar cells are concerned, transparent semiconductor materials such as undoped SnO_2 , In_2O_3 , and ZnO are sufficient for crystalline applications as high-resistive transparent layers in highly efficient CuInGaSe_2 (CIGS) thin-film solar cells. These TSC materials can improve the performance of thin film solar cells such as: Open circuit voltage and fill factor are effectively improved by reducing the distortion of photovoltaic devices. Among these oxides, SnO_2 has important applications in solar cells due to its low cost, physical stability, and high optical transparency over a wide range of wavelengths (Sibel Gurakar et al. 2014). Tin dioxide (SnO_2) is a type of high-bandgap semiconductor material and is widely used in solar cells, energy-saving devices, antistatic films, electromagnetic wave shielding materials,

etc. In recent years, many attempts have been made to add highly conductive n-type and p-type SnO_2 by doping. SnO_2 thin films can be manufactured by various techniques Chemical vapor deposition (CVD), organometallic deposition, RF sputtering, sol-gel dip coating, spin coating, spray pyrolysis. It has been clearly demonstrated that the structure, electron transport and optical properties of SnO_2 films are highly sensitive to the fabrication method, deposition conditions, doping atoms, and number of doping atoms [T. Serine et al. 2005]. Among the various deposition techniques, dip coating is the most suitable for producing thin surface coatings of tin dioxide and is preferably used in industrial and solar applications.

Recently, much research has focused on this SnO_2 thin films. However, they have achieved good results through complex experimental procedures. Here, a very simple and economically affordable process (dip coating) is used to create SnO_2 thin films. Therefore, experimental studies of the band structure, electrical and optical properties of SnO_2 thin films are highly desirable. In this project, we wanted to investigate the effects of electrical transport and optical mechanisms in SnO_2 and Al doped SnO_2 thin films.

CHAPTER 2

LITERATURE SURVEY

2.1 A Featural Analysis of Aluminium Doped SnO₂ and Bare SnO₂ Thin Films Grown on FTO Substrates:

J. Kethzy Agnes investigates the effects of aluminium doping on the properties of tin oxide (SnO₂) thin films grown on the FTO substrates. Previous research has reported on the effect of aluminium doping on the structural, optical, and gas sensing properties of SnO₂ thin films, as well as the growth and characterization of SnO₂ thin films on FTO substrates using various techniques such as sputtering, chemical vapour deposition, and sol-gel methods. The results of this study could have important implications for the development of SnO₂ based materials for various applications such as gas sensing, energy conversion, and optoelectronics.

2.2 Morphological and Structural Properties of spin coated Tin Oxide thin films:

Mohamed Shaban investigates the effect of deposition parameters on the morphological and structural properties of spin-coated tin oxide (SnO₂) thin films using various characterization techniques. Tin oxide thin films have potential applications in various fields and spin coating is a popular and cost-effective technique for their fabrication. Previous studies have also reported on the morphological and structural properties of SnO₂ thin films using different deposition techniques and characterization methods. The result of this study could provide important insights into optimisation of deposition parameters for the fabrication of SnO₂ thin films with desired morphological and structural properties.

2.3 Preparation and characterization of Nickel and Aluminium-Codoped SnO₂ Thin films for Optoelectronic Applications:

El Mahdi Bouabdalli investigates the preparation and characterization of the nickel and aluminium-codoped tin oxide (SnO₂) thin films for optoelectronic applications. The authors used sol-gel method to prepare the thin films and investigated the effect of doping concentration on their optical and structural properties using various

characterization techniques, including X-ray diffraction (XRD), scanning electron microscopy (SEM), and UV-visible spectroscopy.

Tin oxide thin films doped with different elements have been widely studied due to their potential applications in various fields such as solar cells, gas sensors, and transparent conductive coatings. Previous research has reported on the preparation and characterization of SnO₂ thin films doped with various elements including nickel and aluminium using different deposition methods and characterization techniques.

2.4 The influence of Al doping on optical, electrical, and structural properties of transparent and conducting SnO₂: Al thin films prepared by spray pyrolysis technique:

Maxwell Mageto investigates the effect of aluminium doping on the properties of tin oxide (SnO₂) thin films prepared by spray pyrolysis technique. The authors varied the doping concentration and characterized the resulting changes using various techniques. SnO₂ thin films doped with different elements have potential applications in various fields, and the spray pyrolysis technique is a popular method for their fabrication. Previous studies have also reported on the influence of aluminium doping on the properties of SnO₂ thin films. The results of this study could provide important insights for the optimization of doping concentration in the fabrication of SnO₂ thin films with desired properties.

2.5 Conductivity type inversion and optical properties of aluminium-doped SnO₂ thin films prepared by sol-gel spin coating technique:

S. S. Soumya prepared the ATO thin films using the sol-gel spin coating technique and investigated their electrical and optical properties. They observed that the conductivity type of the thin films inverted from n-type to p-type with increasing aluminium doping concentration. The authors attributed this behaviour to the formation of oxygen vacancies and aluminium interstitials.

In terms of optical properties, the authors found that the transmittance of the ATO thin films decreased with increasing aluminium doping concentration. Additionally, the energy band gap of the thin films decreased with increasing aluminium doping concentration. The authors explained this behaviour as a result of the Burstein-Moss effect, which arises due to the doping induced increase in the carrier concentration.

Overall, the paper provides insights into the electrical and optical properties of ATO thin films, which have potential applications in optoelectronics and energy conversion devices.

2.6 Structural and physical properties of tin oxide thin films for optoelectronic applications:

Su-Shia Lin investigates the structural and physical properties of tin oxide (SnO_2) thin films for optoelectronic applications. The authors prepared the thin films using a sol-gel method and characterized their properties using various techniques, including X-ray diffraction (XRD), scanning electron microscopy (SEM), and UV-visible spectroscopy.

Tin oxide thin films have potential applications in various fields such as solar cells, gas sensors, and transparent conductive coatings. The result of this study provides insights into the optimization of the sol-gel process for the preparation of SnO_2 thin films with desired structural and physical properties. This could be important for the development of SnO_2 - based materials for optoelectronic applications.

2.7 Deposition of tin oxide thin film by sol-gel dip coating technique and its characterization:

B. R. Aswathy synthesized the SnO_2 sol-gel precursor using tin chloride and deposited the thin films on glass substrates by dip-coating. The thin films were then annealed at different temperatures to investigate the effect of annealing on the structural, morphological, and optical properties of thin films.

The authors observed that the deposited thin films had an amorphous structure, which transformed into a crystalline structure upon annealing. The annealing temperature was found to affect the crystalline phase of the films, with the highest crystallinity observed at 600°C .

In terms of morphology, the authors found that the thin films exhibited a uniform and dense microstructure. The optical properties of the thin films were investigated by measuring the transmittance and reflectance spectra, and the authors found that the films exhibited high transmittance in the visible region with a bandgap of 3.86 eV.

Overall, the paper provides insights into the sol-gel dip coating technique for the deposition of SnO₂ thin films and the effect of annealing temperature on the structural and optical properties of the films.

2.8 Synthesis and Characterization of SnO₂ thin layer with a doping Aluminium is deposited on Quartz substrates:

Aris Doyan used the sol-gel technique to prepare the ATO precursor solution, and then deposited the thin films on quartz substrates using spin coating method. The ATO thin films were characterized using various techniques.

They observed that the as deposited ATO thin films had a crystalline structure with a preferred orientation along the (110) plane. The doping of aluminium into the SnO₂ lattice was found to decrease the crystallite size of the films. The morphology of the films was found to be uniform and dense.

In terms of optical properties, the authors found that the ATO thin films exhibited high transmittance in the visible region with a bandgap of 3.77 eV. The authors also investigated the electrical properties of the ATO thin films and found that the films exhibited a decrease on resistivity with increasing aluminium doping concentration.

Overall, the paper provides insights into the synthesis and characterization of ATO thin films, which have potential applications in various fields such as solar cells, gas sensors, and transparent conductive electrodes. The study also highlights the potential of the sol-gel spin coating technique for the fabrication of ATO thin films on quartz substrates.

CHAPTER 3

AIM AND SCOPE

3.1 Aim:

Our aim is to synthesize SnO_2 and Al-doped SnO_2 thin films on non-conductive substrates and to analyse the properties of the films. Synthesis is mainly focused on solar cell applications. Dip coating was chosen because it is very difficult to synthesize coatings, especially for SnO_2 films, by this method. As our research topic, we plan to optimize the technique and synthesize SnO_2 and Al-doped SnO_2 films. In this work we studied the structural, optical, and electrical properties of Aluminium doped tin oxide thin films deposited on glass substrate.

3.2 Scope:

Renewable energy sources are needed due to the current high-power consumption and lack of non-renewable energy sources. The scope of this project is primarily for solar cell applications. Therefore, we planned research on metal oxide thin films with the aim of improving the efficiency of solar cells. SnO_2 is widely used in many fields due to its excellent optical and electrical properties. Tin oxide is a typical wide bandgap n-type transparent semiconductor. In this paper, our goal is formation of p-type tin oxide thin film using n-type Tin-Aluminium doped oxide material. Aluminium is a p-type extrinsic dopant used in thin film technology. Therefore, we choose aluminium as the dopant for the preparation. It is made of a thin film of p-type tin oxide. P-type transparent conductive oxide materials are used in thin film transistor applications, gas sensing, functional windows, and photovoltaics, industrial and optoelectronic applications.

CHAPTER 4

MATERIALS AND METHODOLOGY

4.1 Materials:

4.1.1 Stannous Chloride Dihydrate:

Chemical Name : Stannous Chloride Dihydrate

Chemical Formula : $\text{SnCl}_2 \cdot 2\text{H}_2\text{O}$

Molar Weight : 225.6 mol/g

Melting Point : 37-38° C/lit

Boiling Point : 652° C/lit

Density : 2.71 g/cm³

IUPAC Name : Tin(II) Chloride

Solubility : Hydrochloric Acid

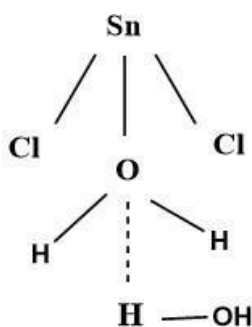


Fig.4.1.1. Structure of Stannous Chloride Dihydrate

Tin chloride dihydrate is a compound with the molecular formula $\text{SnCl}_2 \cdot 2\text{H}_2\text{O}$. Also known as stannous chloride dihydrate or stannous dichloride dihydrate. The compound is a white crystalline solid, highly soluble in water, with a melting point of 37.7 °C.

Stannous chloride dihydrate is commonly used in various industries such as pharmaceutical, chemical and textile industries. In the pharmaceutical industry, it is used as a reducing agent and catalyst in various chemical reactions. It is also used in the textile industry as a mordant to help fix dyes on fabrics.

In addition, stannous chloride dihydrate is also used to make tinfoil, which is a thin steel sheet coated with a layer of tin. It is used to manufacture a variety of products, including metal containers such as cans.

Tin chloride dihydrate is also used as a reagent to detect gold and other precious metals in the laboratory. It is also used in analytical chemistry to measure mercury and other heavy metals. However, it is important to note that stannous chloride dihydrate can be dangerous if not handled properly. May cause skin and eye irritation and may be harmful if ingested or inhaled. Therefore, appropriate safety precautions should be taken when handling this compound.

4.1.2 Ethanol:

Chemical Name : Ethyl Alcohol

Chemical Formula : $\text{CH}_3\text{CH}_2\text{OH}$

Molar Weight : 46.069 g/mol

Melting Point : -114°C

Boiling Point : 78.24°C

Density : 0.7893 g/cm^3

IUPAC Name : Ethanol

Solubility : Water

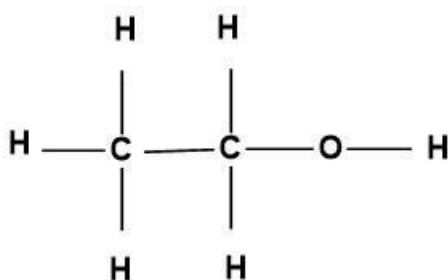


Fig.4.1.2. Structure of Ethanol

Ethanol, also known as ethyl alcohol, is a clear, colourless, flammable liquid that is widely used as a solvent, fuel, and intoxicating drink. Its chemical formula is $\text{C}_2\text{H}_5\text{OH}$ and it is one of the most commonly used alcohols.

Ethanol is produced by the fermentation of sugars and starches in grains, fruits and vegetables by yeast and other microorganisms. It is also produced by hydration of ethylene gas or catalytic reduction of acetaldehyde.

One of the best-known uses of ethanol is its use as an alcoholic beverage. Consumed in many forms, including beer, wine, and spirits, it has been part of human culture for thousands of years. However, excessive ethanol consumption can lead to a variety of health problems, including liver damage, heart disease, and poisoning.

Ethanol is also used as a fuel, either alone or mixed with gasoline. It is a renewable, bio-based alternative to petroleum-based fuels and emits less pollutants such as carbon monoxide and particulate matter.

Additionally, ethanol is a versatile solvent and is used in the production of various consumer products such as perfumes, cosmetics, and cleaning products. It is also used in the pharmaceutical industry as a solvent and as a preservative in pharmaceuticals.

However, ethanol is highly flammable and dangerous if mishandled. Store in a well-ventilated area away from heat and sources of ignition. It is also important to note that ethanol is toxic in large amounts and can cause serious health problems and even death.

4.1.3 Aluminium Nitrate Nonahydrate:

Chemical Name : Aluminium Nitrate

Chemical Formula : $\text{Al}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$

Molar Weight : 375.134 g/mol

Melting Point : 72.8° C

Boiling Point : 135° C

Density : 1.72 g/cm³

IUPAC Name : Aluminium Trinitrate Nonahydrate

Solubility : Cold Water

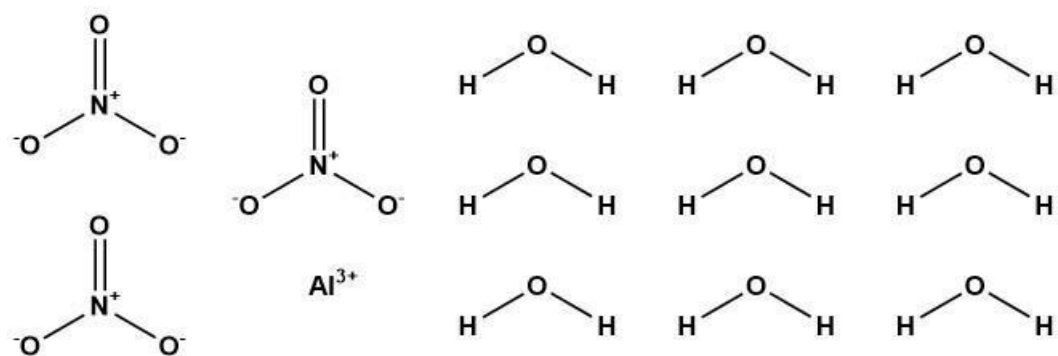


Fig.4.1.3. Structure of Aluminium Nitrate Nonahydrate

Aluminium nitrate nonahydrate is a compound with the molecular formula $\text{Al}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$. It is a white crystalline solid that is highly soluble in water and has a melting point of 73 °C. This compound is also known as aluminium nitrate hydrate or aluminium nitrate nonahydrate.

Aluminium nitrate nonahydrate is also used in the production of other aluminium compounds such as aluminium hydroxide and aluminium oxide used in the production of ceramics, refractories, and other materials.

Thin films made with aluminium nitrate nonahydrate can be used in a variety of applications, including electronic device manufacturing, protective coatings, and optical materials. However, it is important to note that proper safety precautions should be taken when handling aluminium nitrate nonahydrate as it can be dangerous if mishandled.

4.2 Methodology:

4.2.1 SnO₂ Thin Film Deposition Method:

4.2.1.1 Dip Coating Process Theory:

Dip coating is the process of applying thin layers to various substrates such as metals, glasses, and ceramics. In this process, the substrate is immersed in a liquid solution of coating material and withdrawn at a controlled rate to create a thin film of coating material.

The dip coating process is based on the theory of fluid mechanics and surface tension. When a substrate is immersed in a liquid solution, the liquid forms a thin film on the surface of the substrate due to surface tension. When the substrate is pulled out of the solution, the liquid film adheres to the surface of the substrate and forms a uniform coating.

Coating thickness is determined by drawing speed, solution viscosity, and liquid surface tension. A slow drawing speed results in a thicker coating, and a faster drawing speed results in a thinner coating. The viscosity of the solution also affects the thickness of the coating, with a more viscous solution producing a thicker coating.

A dip coating process can also be used to produce multiple coating layers by repeating the dipping and picking up process. This is known as multi-layer dip coating and is commonly used in the production of optical coatings such as anti-reflection coatings. It is widely used to produce coatings for various applications such as anti-corrosion, optical coatings, and medical devices.

The dip coating process is a simple and widely used method for applying thin layers to various substrates. The dip coating process steps are:

Preparation of coating solution:

A solution of the coating material is prepared in a suitable solvent. Solution concentration and viscosity are key factors in determining coating thickness and quality.

Substrate preparation:

Clean and dry the substrate to remove contaminants that may affect coating adhesion. The substrate may also be pre-treated with a primer or adhesion promoter to improve adhesion of the coating.

Dipping the substrate:

The substrate is immersed in the coating solution at a controlled rate and held in the solution for a predetermined period of time to allow the liquid to wet the surface of the substrate.

Withdrawal of the substrate:

The substrate is slowly pulled out of the coating solution at a controlled rate to drain excess solution and form a uniform coating on the surface of the substrate.

Drying or curing the coating:

The coated substrate is dried or cured at a suitable temperature and time depending on the nature of the coating material and desired properties of the coating.

Optional steps:

Multiple coatings can be applied by repeating the dip-and-dump process to produce multilayer coatings. After the final coating, the substrate may undergo post-treatment processes such as annealing, polishing, or surface modification to improve coating performance.

Overall, the dip coating process is a simple and versatile method for producing thin layers on various substrates. It is widely used to produce coatings for various applications such as anti-corrosion, optical coatings, and medical devices.

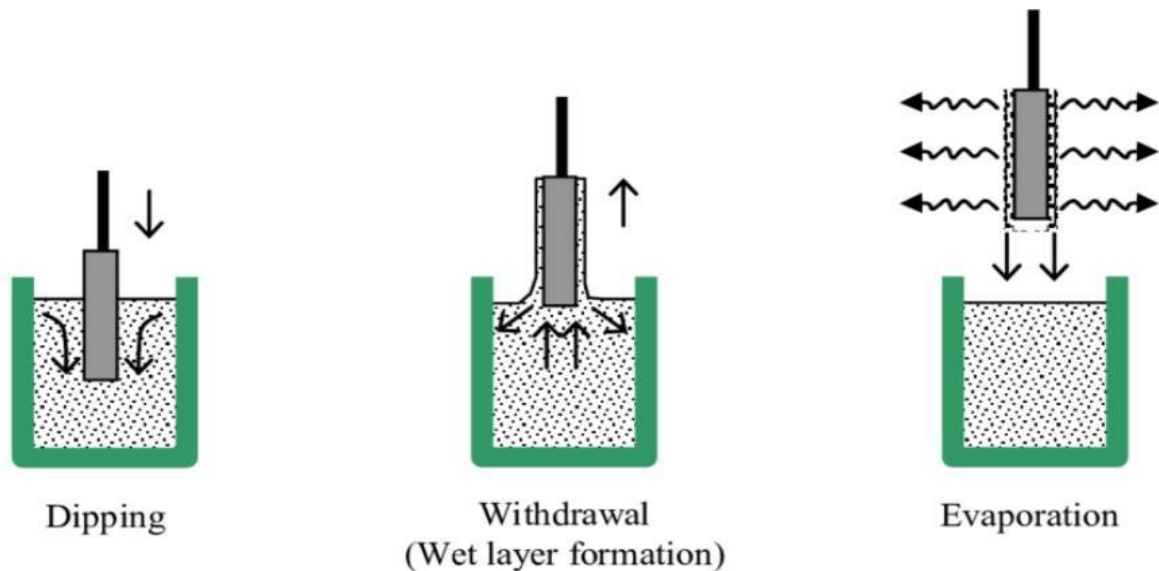


Fig.4.2.1. Schematic diagram of Dip Coating Process

4.2.1.2 Advantages of Dip Coating:

Simple and cost-effective:

The dip coating process is a simple and inexpensive process that does not require expensive equipment or complicated procedures.

Uniform coating:

The dip coating process produces an even and consistent coating on the substrate surface. Thickness can be controlled by adjusting the draw speed and concentration of the coating solution.

Versatility:

Dip coating processes can be used to apply a wide range of coating materials including polymers, metals, ceramics, and composites to a variety of substrates including metals, glasses, plastics, and ceramics.

High Throughput:

The dip coating process can be easily scaled up to mass production, allowing a single dip coating solution to coat multiple substrates simultaneously.

Multilayer coating:

The dip coating process can be used to produce multiple coating layers by repeating the dip and strip process. This allows the production of complex coatings with specific properties.

Environmentally Friendly:

The dip coating process is a low cost and environmentally friendly process as it minimizes waste and uses only a small amount of coating material.

4.2.1.3 Disadvantages of Dip Coating Process:

Limited coating thickness:

The dip-coating process is generally suitable for producing thin films up to a few microns thick. If a thicker coating is required, another coating process should be considered.

Low precision:

The dip coating process is less accurate than other coating processes such as Spray coating or spin coating, and can lead to uneven coating or unevenness.

Time consuming:

The dip coating process can be time consuming, as the substrate must be dipped and withdrawn multiple times to achieve the desired coating thickness.

Limited range of substrates:

The dip coating process is not suitable for all substrates and may not adhere well to certain substrates or surfaces.

Limited control of coating properties:

The dip coating process does not allow for precise control of certain coating properties such as porosity, roughness, and adhesion.

4.2.1.4 Applications of Dip Coating:

Protective coating:

Dip coating can be used to apply protective coatings to a variety of surfaces including metals, glass, ceramics, and plastics. Coatings can improve substrate resistance to corrosion, abrasion, and environmental degradation.

Optical coating:

Dip coatings can be used to apply thin films of materials that exhibit optical properties such as antireflection, colour, or light absorption. These coatings can be applied to lenses, mirrors, or other optical components.

Medical coating:

Dip coating can be used to apply biocompatible coatings to medical implants or devices such as stents, catheters, and prostheses. These coatings improve the biocompatibility of the device and reduce the risk of rejection and infection.

Energy storage:

Dip coating can be used to apply thin films of materials that exhibit electrochemical properties such as: Battery electrodes or supercapacitors. These coatings can improve the efficiency and performance of energy storage devices.

Sensor:

Dip coating can be used to apply thin layers of materials that exhibit sensing properties such as gas sensors, biosensors, and humidity sensors. These coatings can improve the sensitivity and selectivity of the sensor.

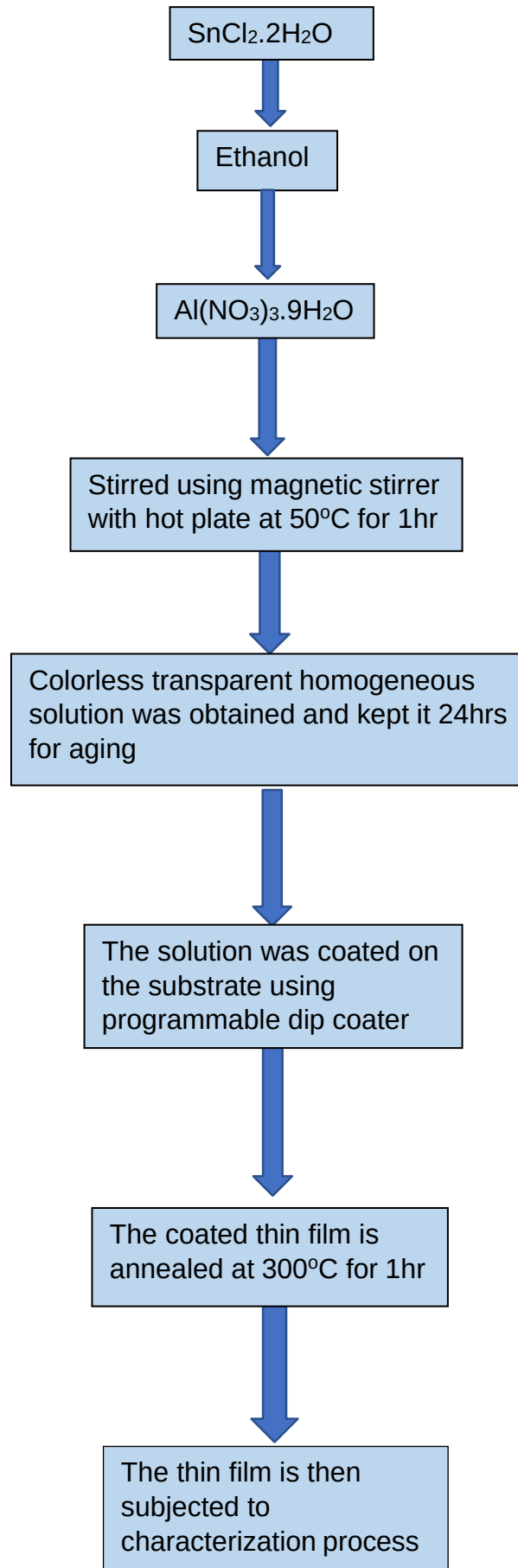
Automotive coating:

Dip coating can be used to apply automotive coatings to a variety of surfaces including metal parts, plastic parts, and glass. Coatings can improve appearance, durability, and resistance to environmental influences such as UV light, chemicals, and weathering.

4.2.2 Experimental procedure:

Initially, 5.9493 millimoles of $\text{SnCl}_2 \cdot 2\text{H}_2\text{O}$ was dissolved in 10ml of absolute ethanol. This inhomogeneous solution is stirred for 1 hour at 50°C by using magnetic stirrer with hot plate in order to make a homogeneous solution. Then $\text{Al}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$ was added to the above solution in various concentrations. After stirring, the solution is kept for 24 hours. Then this homogeneous solution is coated on the glass substrate which is basically a non-conducting medium by using a programmable dip coater. Finally, the thin film has formed on the substrate in an ambient atmosphere at 30 or 50 dips, the coated substrate is annealed at 300°C for 1 hour.

4.2.6 Flowchart of Synthesis process:



CHAPTER 5

RESULT AND DISCUSSION

5.1 X-Ray diffraction:

X-Ray diffraction is a powerful analytical technique used to study the atomic and molecular structure of materials. It involves shining a beam of X-rays onto a sample and observing the diffraction pattern of the X-rays as they interact with the atoms in the material.

The X-ray diffraction pattern provides information about the arrangement of atoms in the crystal lattice of the material, including the spacing between atoms and the angles between crystal planes. This information can be used to determine the crystal structure of the material, as well as its composition and other physical properties.

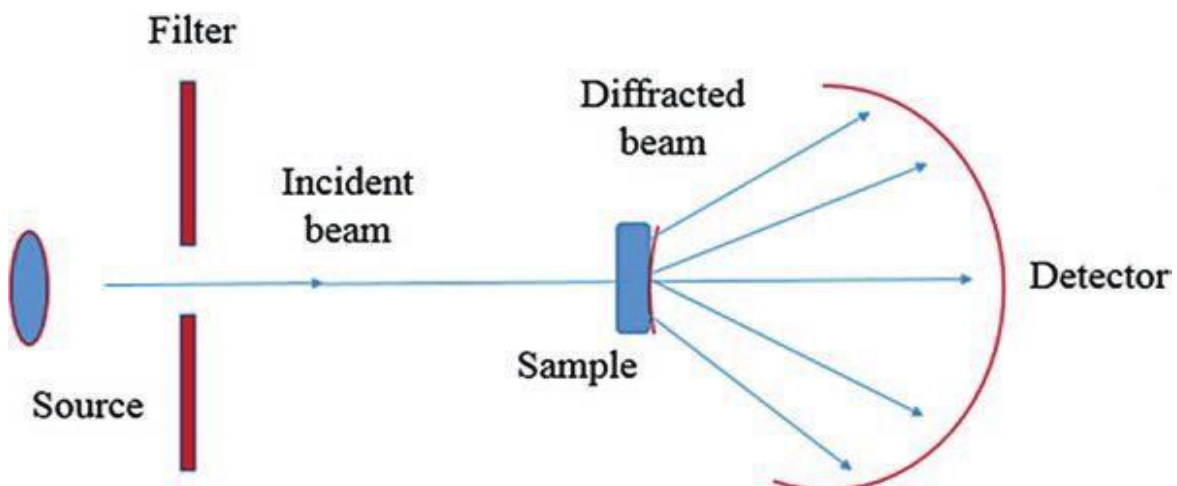


Fig.5.1.1. Schematic diagram of X-Ray Diffraction

X-ray diffraction is based on the principle of Bragg's law $2d\sin\theta = n\lambda$, which states that when X-rays strike a crystal lattice at a certain angle, they will be diffracted at specific angles that depend on the spacing between atoms in the lattice.

The basic working principle of XRD involves directing a beam of X-rays onto a sample, typically a crystalline material, at a specific angle. As the X-rays interact with the atoms in the crystal lattice, they are diffracted at specific angles, producing a diffraction pattern that can be detected by a detector.

The diffraction pattern is a series of spots or peaks that correspond to the specific angles at which the X-rays are diffracted by the crystal lattice. By analysing the positions and intensities of the diffraction peaks, it is possible to determine the crystal structure of the material, as well as its composition and other physical properties.

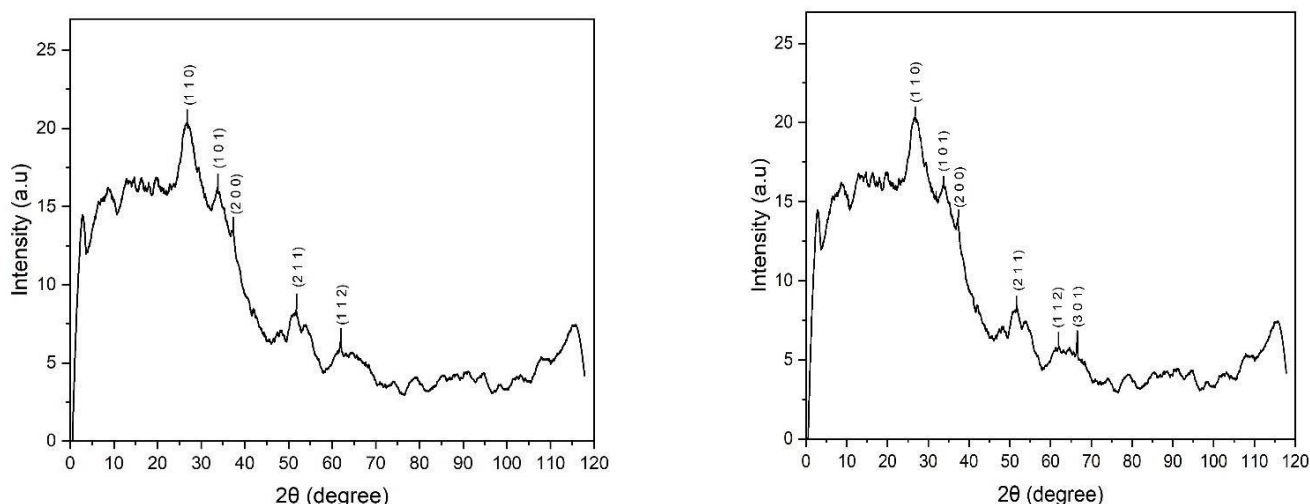


Fig.5.1.2. XRD pattern of SnO₂ and AlSnO₂.

The XRD pattern of the SnO₂ and Al-SnO₂ is shown above. The peaks at 2θ values of 26.8709, 33.4677, 37.2668, 51.1966, and 62.0048 can be associated with (1 1 0), (1 0 1), (2 0 0), (2 1 1), and (1 1 2) respectively. The X-ray diffraction pattern revealed that the deposited thin film has tetragonal crystal structure with preferable orientation along (1 1 0) plane which are in good agreement with the values (JCPDS No.41-1445).

5.2 UV-Visible Spectroscopy:

UV-VIS spectroscopy is based on the measurement of light absorbance across the ultraviolet (UV) and visible (VIS) regions of the electromagnetic spectrum with wavelength ranges of 200-800 nm. Incident light hits matter which can either be absorbed, reflected, or transmitted. The absorbance of radiation in the UV-Vis range causes atomic excitation, which refers to the transition of molecules from a low-energy ground state to an excited state.

The working principle of UV spectroscopy is based on the Beer-Lambert principle. When a monochromatic light beam passes through a solution of an absorbing material, the rate at which the intensity of the radiation decreases with the thickness

of the solution is proportional to both the incident radiation and the concentration of the solution.

$$A = \log(I_0/I) = \epsilon cl$$

A – Absorbance; I_0 - Intensity of incident light; I - Intensity of emission of light from the sample; ϵ – Molar extinction coefficient (measure of probability of electronic transition); c – Concentration of absorbing species; l – Distance covered by the light through the solution.

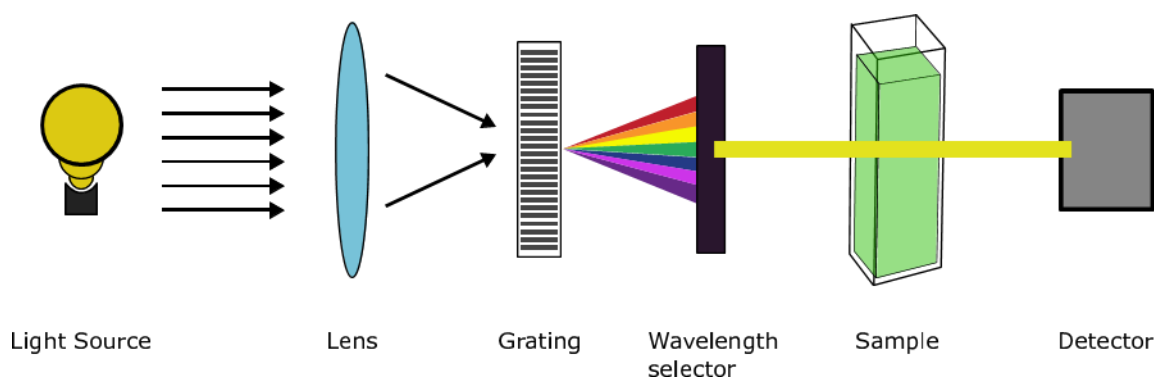


Fig.5.2.1. Schematic diagram of UV-Visible Spectroscopy

When a sample is placed in a spectrophotometer, it absorbs light at specific wavelengths determined by its chemical composition and structure. The detector measures the remaining light as it passes through the sample. The detector converts the intensity of the light into an electrical signal, which is then displayed on the screen as an absorbance versus wavelength spectrum.

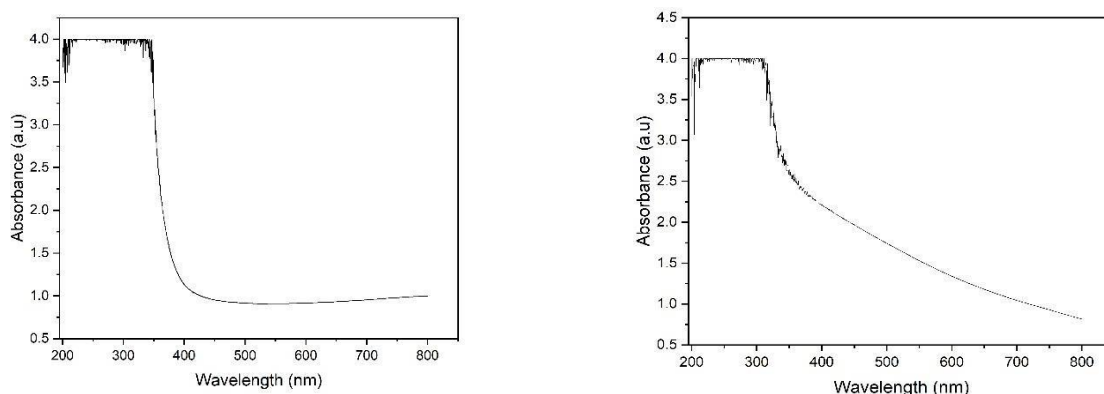


Fig.5.2.2. Absorption Spectra of SnO₂ and AlSnO₂

The absorbance spectrum of SnO_2 and AlSnO_2 has been obtained by using UV-Vis Spectroscopy technique. The figure 5.2.A illustrates that the maximum absorbance of SnO_2 and AlSnO_2 is about between 3.5 to 4.0 a.u. and it has maximum from 223.5nm to 337nm cut off frequency, which indicates that it absorbs maximum radiation in the UV region and decrease gradually in the visible region. We know that in the day time, the Earth's surface receives more UV radiation from the Sun than the night (receive IR radiation). Therefore, SnO_2 and AlSnO_2 thin films are suitable for solar cell application.

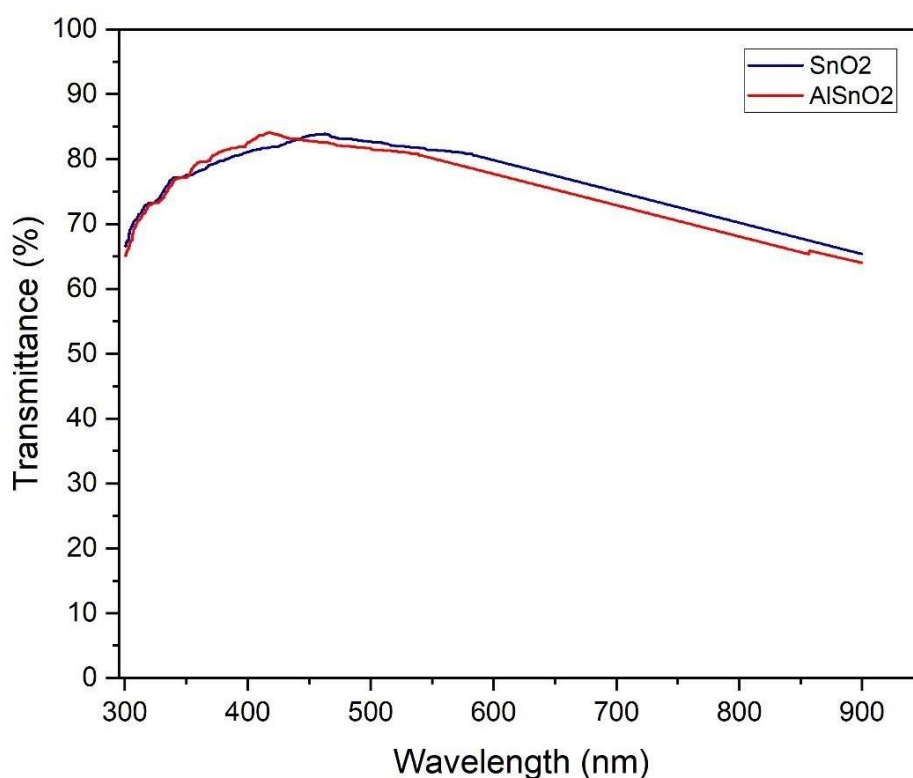


Fig.5.2.3. Transmittance % of SnO_2 and AlSnO_2

The transmittance spectrum of SnO_2 and AlSnO_2 thin film has been obtained using UV-Visible spectroscopy technique. The figure 5.2.B shows that the maximum transmittance of SnO_2 and AlSnO_2 is about 75-85%, and the cut off frequency is 295nm. From the transmittance it is clear that SnO_2 and AlSnO_2 can transmit more amount of energy than CdTO , CdO , ZnO thin films [E. Muchuweni (2017), Faisal G. Hammoodi (2022)]. Basically, the energy conversion is depending on how much the solar radiation can transmit through the coating material. Also, this transmittance of SnO_2 and AlSnO_2 has good agreements with results of [Aris Doyan et al. (2017)]

5.3. Band Gap Analysis:

An alternative strategy is to use layers of different materials onto the silicon base material now a days. This employed in the solar industry in the construction of photovoltaic solar cells. The bandgap is important as it determines the portion of the solar spectrum a photovoltaic cell absorbs. Much of the solar radiation reaching the Earth is comprised of wavelengths with energies greater than the bandgap of silicon. These higher energies will be absorbed by the solar cell, but the difference in energy is converted into heat rather than into usable electrical energy. Consequently, unless the bad gap is controlled, the efficiency of the solar cell will be poor. Using layers of different materials with different bandgap properties is a proven way to maximize the efficiency of solar cells. Therefore, the material which is coated on a silicon substrate should have the bandgap greater than the silicon material, so that it can absorb more energy from the solar radiation.

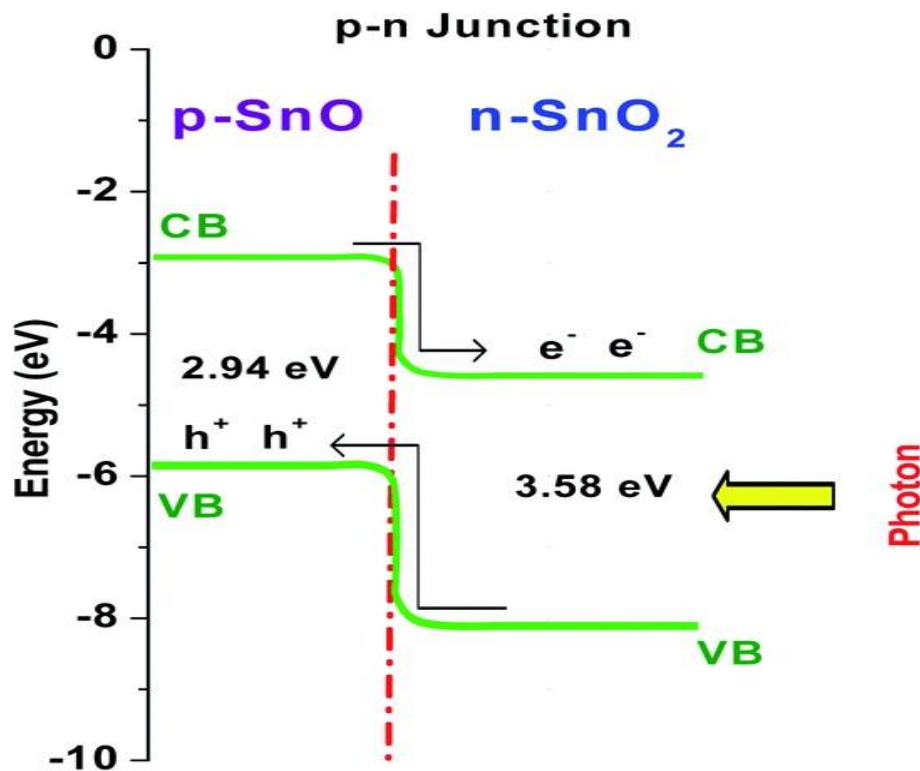


Fig.5.3.1. Typical Band Gap structure of SnO₂

The fundamental absorption, which corresponds to electron excitation from the valence bond to conduction band, can be used to determine the nature and value of optical band gap. The absorbance may also depend on some of the properties like oxygen deficiency, nature of the surface and impurity centres.

The absorbance of the film is decreased in an apparent way with wavelength near the IR region. The absorption coefficients (α) were determined by means of the optical absorbance spectra using the relation, $\alpha = (1/d) \ln(1/A)$ where d is the thickness and A is the absorbance of the film at a particular wavelength.

The optical band gap E_g of the thin film was calculated using the Tauc's relation which is given by,

$$(\alpha h\nu)^{1/n} = A(h\nu - E_g)$$

Where A is a constant and E_g is the band gap of the material and exponent n depends on the type of transition. For direct allowed $n=1/2$, indirect allowed transition $n=2$, and for direct forbidden $n=3/2$.

To determine the possible transitions, $(\alpha h\nu)^{1/n}$ vs. $h\nu$ was plotted and corresponding band gap was obtained from extrapolating the straight portion of the on $h\nu$ axis at $\alpha=0$. The plot of $(\alpha h\nu)^2$ versus $h\nu$ is shown in figure 5.3.

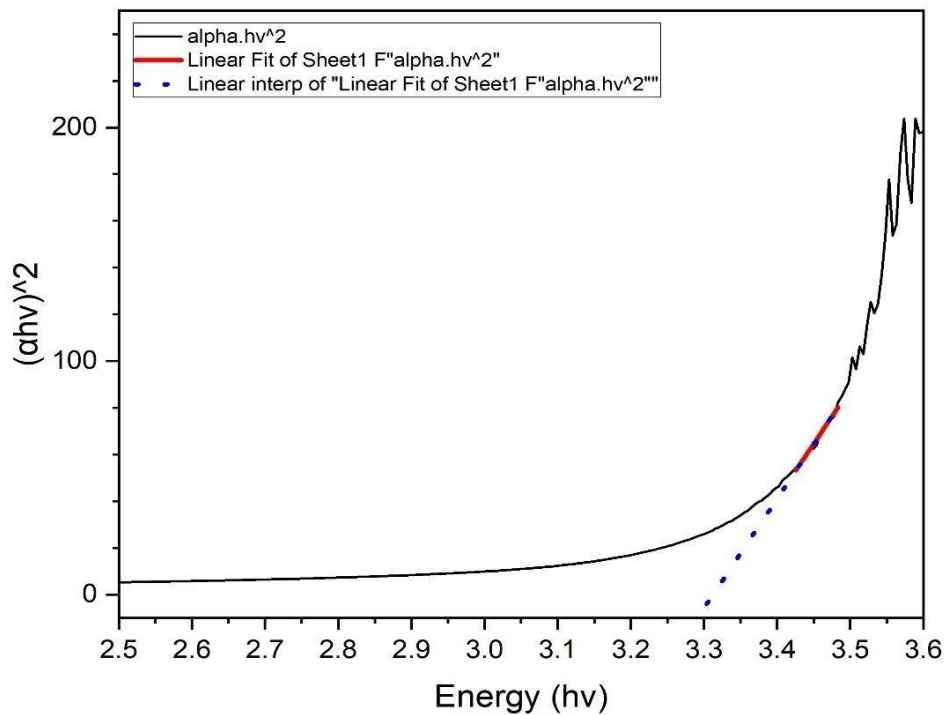


Fig.5.3.2. Band Gap graph of SnO₂ thin film.

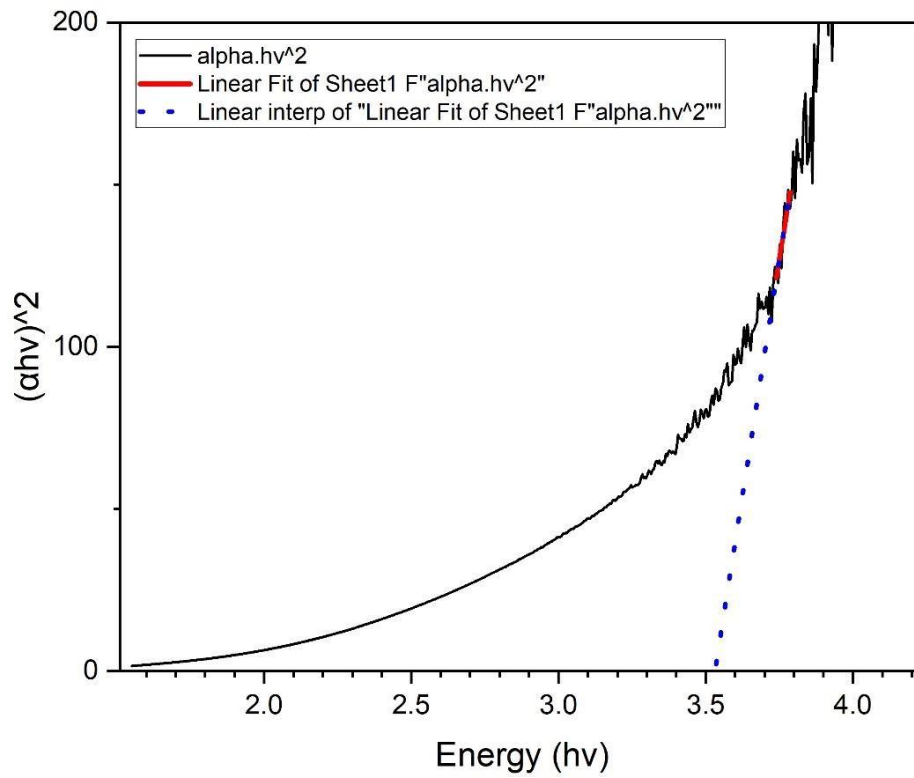


Fig.5.3.3. Band Gap graph of AlSnO₂ thin film.

The optical energy band gap was obtained by extrapolating the linear portion of $(\alpha h\nu)^2$ versus $h\nu$ plot gives 3.28 and 3.5 eV for SnO₂ and AlSnO₂ thin film respectively. The band gap value is matched with S. S. Soumya et al, (2021), Aris Doyan et al, (2017).

5.4 Hall Effect Measurement:

An electric current (electrons) flowing through a material is created by the action of a magnetic field on the current (electron). Because of its discovery in a metal, the Hall effect has become widely used in semiconductors, particularly thin films, to characterize their properties. When it comes to semiconductor manufacturing, Hall effect measurements are useful for characterizing practically every material that is employed. For the examination of electrical properties in semiconductor materials, such as resistivity, carrier density, and mobility, the Van Der Pauw method can be used to calculate samples of any shape, several basic sample conditions must be met in order to obtain accurate measurements.

For example, the thickness of the sample must be constant, point contacts placed at the edges of the samples must be used to take measurements, and the sample quality must be homogeneous. Because most semiconductor samples meet these requirements, this easy testing method is frequently used in semiconductor research.

To create high performance innovative devices, most semiconductor thin films are now in research. A straightforward measurement method for evaluating semiconductor thin films, the Van Der Pauw method is described here. Consequently, new thin films will occasionally be assessed using the Van Der Pauw method to establish film quality as a reference, independent of their homogeneity, in order to determine film quality.

Hall effect measurements were done for all the samples at room temperature using Ecopia HMS 3000. The Hall effect measurement instrument HMS 3000 is a scientific instrument used to measure the Hall effect in materials. The Hall effect is a phenomenon in which a magnetic field applied perpendicular to a current-carrying conductor induces a voltage difference across the conductor. This effect is used to measure the electrical properties of materials, such as conductivity, carrier concentration, and mobility.

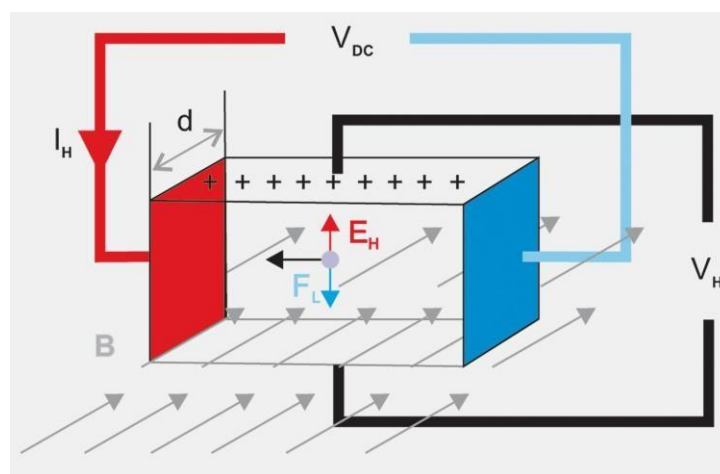


Fig.5.4.1. Schematic diagram of Hall effect measurement

To use the HMS 3000 for measuring thin films, the sample must be carefully prepared and mounted onto the instrument. The sample should be clean and free of any contaminants or debris that could affect the measurement. The sample is typically mounted onto a flat, non-conductive substrate that can withstand the vacuum environment of the measurement chamber.

Once the sample is mounted, the HMS 3000 is used to apply a magnetic field perpendicular to the thin film and measure the resulting Hall voltage. The instrument can also measure the resistance of the sample, which is useful for calculating the carrier concentration and mobility of the thin film.

The HMS 3000 software allows for precise control over the measurement parameters, such as the magnetic field strength and temperature. The software also provides advanced analysis tools for processing and interpreting the data, including graphs, plots, and calculations.

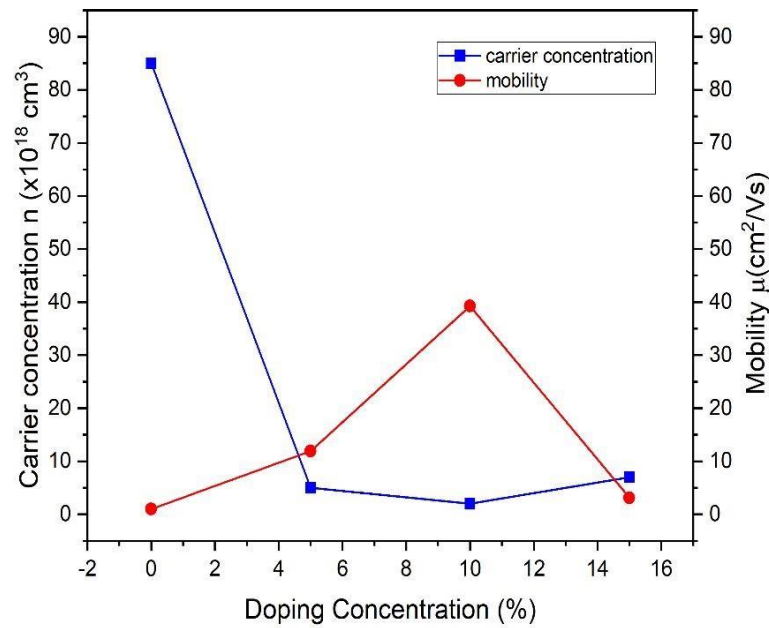


Fig.5.4.2. Variations in the carrier concentration and Hall mobility of SnO_2 and AlSnO_2 thin films as a function of Aluminium doping concentration.

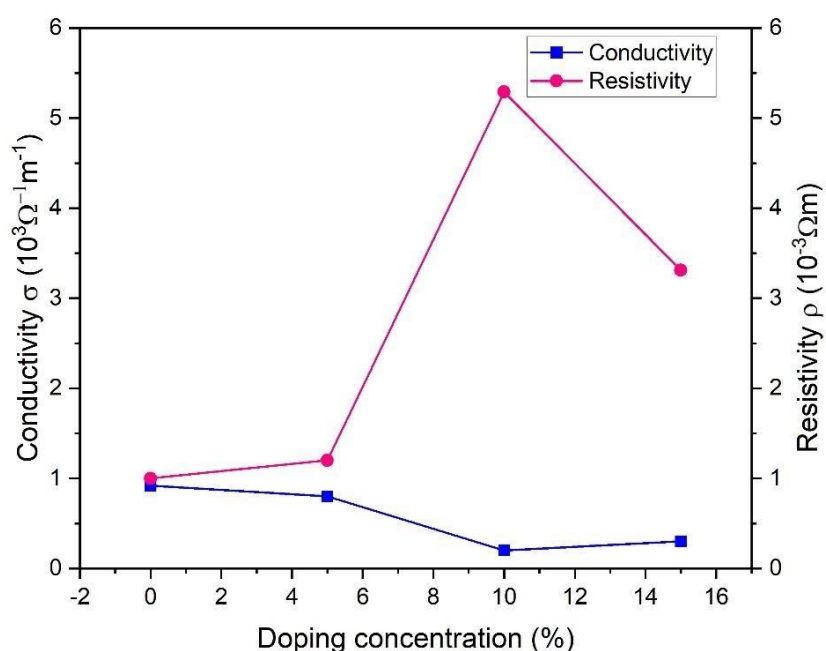


Fig.5.4.3. Variations in the conductivity and Hall resistivity of SnO₂ and AlSnO₂ thin films as a function of Aluminium doping concentration.

A significant change in the electrical properties of the films were observed in terms of the doping concentration of Aluminium. The observed values of charge carrier concentration, mobility, resistivity, and conductivity are given in the below table.

Sample	Charge carrier concentration ($\times 10^{18} \text{cm}^3$)	Mobility (cm^2/Vs)	Conductivity ($\times 10^3 \Omega^{-1} \text{m}^{-1}$)	Resistivity ($\times 10^{-1} \Omega \text{m}$)
SnO ₂	85	1	0.92	1
5AlSnO ₂	5	11.925	0.8	1.2
10AlSnO ₂	2	39.25	0.2	5.29
15AlSnO ₂	7	3.126	0.3	3.31

Table:5.4.1. Values obtained from Hall effect

The conductivity of the films decreases with increase in the aluminium doping concentration up to 10AlSnO₂. But for 15AlSn O₂ the conductivity starts to increase.

Thus, the carrier concentration, resistivity, and conductivity values show the good conductive nature of the SnO₂ and AlSnO₂ thin films.

CHAPTER 6

SUMMARY AND CONCLUSION

The synthesis and characterization of SnO_2 and AlSnO_2 thin films for solar cell applications by using dip coating technique has successfully done. We investigated the structural, optical, and electrical properties of SnO_2 and AlSnO_2 thin films. The X-Ray diffraction pattern revealed that the as deposited film had tetragonal structure with preferable orientation along (1 1 0) plane. The tetragonal structure of all prepared samples was confirmed by X-Ray diffraction spectra.

The optical characteristics such as transmittance and absorbance spectrum of SnO_2 and AlSnO_2 thin films was obtained by UV-Visible Spectrum Analysis. The transmission is about ~80%. Therefore, it found makes suitable for Photo Voltaic Devices. The optical bandgap of Tin Oxide and Aluminium doped Tin Oxide is calculated using Tauc's Plot. The value is about 3.28 eV for SnO_2 and 3.5 eV for AlSnO_2 thin films. It shows the semiconductor behaviour of the thin films.

The absorbance spectrum of SnO_2 and AlSnO_2 has been obtained that the maximum absorbance of SnO_2 and AlSnO_2 is about between 3.5 to 4.0 a.u. and it has maximum from 223.5nm to 337nm cut off frequency, which indicates that it absorbs maximum radiation in the UV region and decrease gradually in the visible region. We know that in the day time, the Earth's surface receives more UV radiation from the Sun than the night (receive IR radiation). Therefore, SnO_2 and AlSnO_2 thin films are suitable for solar cell application.

The electrical properties of the SnO_2 and AlSnO_2 thin films was obtained by Ecopia HMS3000 Hall effect measurement instrument. Thus, the carrier concentration and resistivity values show the good conductivity nature of the SnO_2 and AlSnO_2 thin films. We found that the SnO_2 and AlSnO_2 thin films are suitable for solar cell and photo voltaic application. We are planned to implement this thin film on Solar cell and to correlate our research with theoretical implementation.

CHAPTER 7

RELATED ACTIVITIES AND REFERENCES

7.1 Related Activities:

1. I have actively participated in the one-day certificate program on “UV-Vis Spectrophotometer” organized by Department of Chemistry, Sathyabama Institute of Science and Technology, on 14th February 2023.
2. I have actively participated in the one-day workshop on “Nano Technology For Industry 5.0” organized by Top Engineers at IIT Madras Research Park on 15th April 2023.

7.2 References:

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