

PHYSICAL INTERPRETATION OF PURE AND BISMUTH DOPED SnO₂ THIN FILM IN SOLAR CELL APPLICATION

Submitted in partial fulfilment of the requirements for the award of

Master of Science degree in Physics

By

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**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 AND BISMUTH DOPED SnO_2 THIN FILM IN SOLAR CELL APPLICATION" under my supervision from November 2022 to May 2023.

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I SUNDARESAN. M, hereby declare that the Project Report entitled PHYSICAL INTERPRETATION OF PURE AND BISMUTH DOPED SnO₂ THIN FILM IN SOLAR CELL APPLICATION 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

ACKNOWLEDGEMENT

I am pleased to acknowledge my sincere thanks to Board of Management of SATHYABAMA for their kind encouragement in doing this project and for completing it successfully. I am grateful to them.

I convey my thanks to, Dean, School of Science and Humanities and **Dr. S. RAVICHANDRAN**, Head of the Department, Dept. of Physics for providing me necessary support and details at the right time during the progressive reviews.

I would like to express my sincere and deep sense of gratitude to my Project Guide **Dr. C. RAMESHKUMAR** for her valuable guidance, suggestions and constant encouragement paved way for the successful completion of my project work.

I wish to express my thanks to all Teaching and Non-teaching staff members of the Department of Physics who were helpful in many ways for the completion of the project.

ABSTRACT

This paper investigates the structural, electrical, and optical properties of pure and doped SnO₂ thin films. X-ray diffraction (XRD) was used to examine the crystal structure, while Hall effect and UV-Visible absorption spectroscopy were utilized to assess the electrical and optical properties, respectively. The XRD results showed that the SnO₂ thin film had a tetragonal structure, with a preferential orientation of the (200) plane in both pure and doped samples. Hall effect measurements revealed that the hole concentration and mobility of the doped SnO₂ thin film were higher compared to those of the pure SnO₂ sample. The optical band gap of the doped SnO₂ thin film was estimated to be lower than the pure sample. The results of this study demonstrate that doping SnO₂ with ions can significantly modify the structural, electrical, and optical properties of the SnO₂ thin film, making it suitable for a wide range of optoelectronic applications.

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LIST OF ABBREVIATIONS

PVD	Physical vapor deposition
CVD	Chemical vapor deposition
ALD	Atomic layer deposition
PECVD	Plasma enhanced chemical vapor deposition
EBPVD	Electron beam physical vapor deposition
MBE	Molecular Beam Epitaxy
RPM	Revolution per minute
UV-VIS	Ultraviolet-visible
XRD	X-Ray diffraction
CCD	Charge coupled device
GIXRD	Grazing incidence X-ray diffraction
HRXRD	High-resolution X-ray diffraction
XRR	X-ray reflectivity

CHAPTER 1

INTRODUCTION

1.1 THIN FILM

Energy plays a significant role in the evaluation of human society. As the rate of energy consumption non-renewable source is going to finish as in the future. Currently, technologies are being to produce heat, mechanical and electrical energies from renewable sources. However, the energy produced is not used 100% statistical result shows more than 60% of the energy should be wasted. Mostly the energy should be wasted in the form of heat.

The wasted energies are in the form of heat using thermoelectric materials. This material has the property to convert heat into electrical energy. This material is environment friendly since it does not produce CO₂ emission, they are small, can work in high temperature, is highly reliable, and have a long lifetime.

An effective method to benefit from unused thermal energy is by utilizing thermoelectric substances that possess the ability to transform heat into electrical energy. As a result, implementing systems that employ thermoelectric materials provides numerous benefits such as being eco-friendly, as they do not generate CO₂ emissions on the premises, are compact in size, adaptable to a broad range of temperatures, are dependable, and have a prolonged lifespan.

Tin oxide has been utilized in its powdered form, however, there has been a growing fascination in investigating its nanostructured derivatives, including nanowires, thin films, and nanorods. These derivatives exhibit favorable optical and electrical characteristics which have the potential for further enhancement. It is generally considered an oxygen-deficient n-type semiconductor. It has a bandgap greater than 3 eV, typically ~3.6 eV. Some recent works have focused on the study of Bi-doped SnO₂ films since they have been observed to exhibit insulating properties. For this reason, this oxide with the same dopant could be used in thermoelectric devices. In the work of Chen et al. (2017), the bismuth-doped tin oxide was used in various

proportions to determine the microstructural properties and the transport mechanism found. Bismuth-doped samples showed smaller crystals, a rougher. It was discovered that the electrical resistance experienced a significant surge whereas the electron mobility experienced a decline. As a result, it is expedient to scrutinize the thermoelectric characteristics of this material and ascertain its suitability as a thermoelectric material. surface, and highly disordered structures compared to undoped ones, indicating crystallinity deterioration with increasing Bi doping concentration.

Conventional n-type TCO materials are prepared by various deposition methods such as physical vapor deposition (PVD), thermal evaporation, chemical vapor (CVD), and spray pyrolysis. However, among these deposition methods, the spray pyrolysis (SP) technique is an inexpensive method for the deposition of transparent conducting oxides and other materials such as optical selective coating, magnetic oxide materials, superconductors, and semiconductor thin films. It is a relatively simple and inexpensive technique for large-scale coatings on glass and special substrates at atmospheric pressure.

1.2 IMPORTANCE OF THIN FILM

Typically, thin coatings are employed to enhance the surface characteristics of solids. The utilization of a thin film can enhance various properties of a solid material surface, including but not limited to transmission, reflection, absorption, hardness, resistance to abrasion, corrosion, permeation, and electrical behavior.

Thin films, which are created on a small scale, possess comparable properties to bulk electronic devices. This characteristic of thin films makes them an effective tool for their development. Due to their cost-effective nature, smaller size, and ease of transfer, thin films have become increasingly useful in the field.

1.3 HISTORY OF THIN FILM

For the interest of completeness, a succinct history of thin technology is provided below;

1650: R. Boyle, R. Hooke, and L. Newton see interference patterns (such as oil on water).

1850; the invention of the first deposition procedures (M. Faraday; W. Grove; T. A. Edison) and thickness measurement techniques (Arago, Fizeau, Wernicke, Wiener); commercial introduction of electrochemistry (Galvanics) for gold plating uniform accessories.

Industrial coating production began in 1940; the majority of these uses were for military purposes.

1990; high Tc-Superconductors thin films.

For use as a protective covering and in tribology, nanocrystalline materials with a predetermined composition and structure were produced in 2000. depositing highly organized two- and three-dimensional structures in the nm size range.

Organic electronics (OLEDF, printable circuits) first appeared in 2006 as a result of research into organic covering.

Generation of 2D material-based heterostructures in 2015. methods for producing flexible electrical devices, including ultrathin film.

1.4 PROPERTIES OF THIN FILMS

1.4.1 OPTICAL PROPERTY

Thin films have unique optical properties that differ from bulk materials due to their small thickness and the presence of interfaces.

An important optical property of thin films is reflectance, which is determined by the

film's refractive index and the substrate on which it is deposited. When light hits the film, some light is reflected and the remaining light is transmitted through the film and substrate.

Another important property is the film's transmittance. This is a measure of the amount of light that can pass through the film. This property is affected by the thickness and refractive index of the film as well as the angle of incidence and polarization of the light.

1.4.2 MECHANICAL PROPERTY

Thin films possess an important mechanical attribute called hardness. It represents the film's ability to withstand plastic deformation, scratching, and wear. Due to the existence of grain boundaries and defects, thin films could be harder than their bulk counterparts. These boundaries and defects constrain dislocation motion and magnify the film's strength.

Adhesion to the substrate is a significant mechanical property that measures the effectiveness of bonding between the thin film and substrate. The adhesion factor is critical for ensuring the durability and reliability of thin film coatings. The composition, structure, surface energy of the thin film, surface roughness, and chemistry of the substrate are some factors that can influence adhesion.

1.4.3 ELECTRICAL PROPERTY

Thin films can exhibit varied resistivity properties based on their composition and thickness. Materials with high resistivity can serve as good insulators, whereas low-resistivity materials can be useful in electrical contacts and interconnect.

Thin films composed of conductive substances can demonstrate significant electrical conductivity, which makes them advantageous for various applications like electrodes, sensors, and interconnects.

Thin films are oftentimes employed in capacitive applications such as energy storage and sensing due to their ability to have a high dielectric constant.

1.4.4 CHEMICAL PROPERTY

Thin films can be designed to react with specific chemicals and biomolecules, making them useful for applications such as biosensing and drug delivery. Thin films can be deposited to protect against corrosion, making them useful for applications in harsh environments. Thin films can be deposited with good adhesion to substrates, making them useful for applications such as coatings and adhesives.

1.5 APPLICATION OF THIN FILMS

1. Thin films have a broad range of applications in producing optical coatings, such as polarizers, mirrors, filters, and anti-reflective coatings.
2. Thin films play an important role in manufacturing microelectronic gadgets such as transistors, capacitors, and resistors. Additionally, they are utilized in the creation of displays, touchscreens, and thin-film solar cells.
3. Thin films are applied as protective coatings on different types of surfaces such as metals, plastics, and glass. Additionally, they are utilized as decoration coatings on items such as jewelry, watches, and other consumer goods.
4. Thin films find applications in a variety of sensors such as gas sensors, biosensors, and chemical sensors.

1.6 THIN FILM DEPOSITION TECHNIQUES

Thin film deposition is a process used to create a thin layer of material on a substrate. Several techniques can be used for thin film deposition, including:

1. Physical Vapor Deposition (PVD): PVD is a process in which material is evaporated from a target source and deposited onto a substrate. This can be done

using techniques such as thermal evaporation, electron beam evaporation, or sputtering.

2. Chemical Vapor Deposition (CVD): CVD is a process in which a chemical reaction occurs at the surface of the substrate, resulting in the deposition of a thin film. This can be done using techniques such as plasma-enhanced CVD or low-pressure CVD.
3. Atomic Layer Deposition (ALD): ALD is a process in which thin films are deposited by sequentially exposing the substrate to different gases or vapors, resulting in the controlled growth of a thin film.
4. Spray Pyrolysis: Spray pyrolysis involves the spraying of a precursor solution onto a substrate, which is then heated to decompose the solution and deposit a thin film.
5. Sol-Gel: Sol-gel is a technique in which a precursor solution is applied to a substrate and then heated to form a solid gel, which is then further heated to form a thin film.
6. In spin coating, a liquid solution is applied to a substrate and spun at a high speed to evenly distribute the solution and form a thin film.

1.6.1 PHYSICAL VAPOR DEPOSITION (PVD)

The physical vapor deposition process has the following characteristics: Coatable materials (metals, alloys, ceramics, glasses, polymers) unlimited choice of coatings (metals, alloys, semiconductors, metal oxides, carbides, nitrides, cermets, sulfides, selenides, tellurides) Excellent coating adhesion, easy tuning of microstructure by a selection of coating parameters. be there the following drawbacks of the physical vapor deposition process: The relatively low deposition rate and film thickness coating geometrically complex parts is a complex and technically demanding process. Main fields Applications of the physical vapor deposition process are optical, optoelectronic, and magnetic u thin layers. Microelectronic device. Other

applications can be found in the areas of tribology, corrosion protection and thermal insulation, and decorative coatings among others

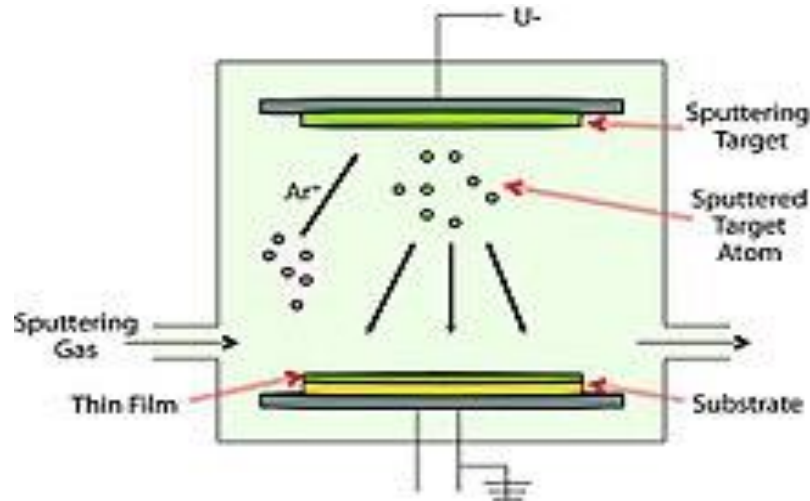


Fig 1.1 Physical vapor deposition method

A. CLASSIFICATION OF PHYSICAL VAPOR DEPOSITION

i. Thermal evaporation method

Thermal evaporation is a common method of physical vapor deposition (PVD). It is one of the simplest forms of PVD and typically uses a resistive heat source to evaporate a solid material in a vacuum environment to form a thin film. The material is heated in a high vacuum chamber until vapor pressure is produced. The removed evaporated material through the vacuum chamber and coats the substrate.

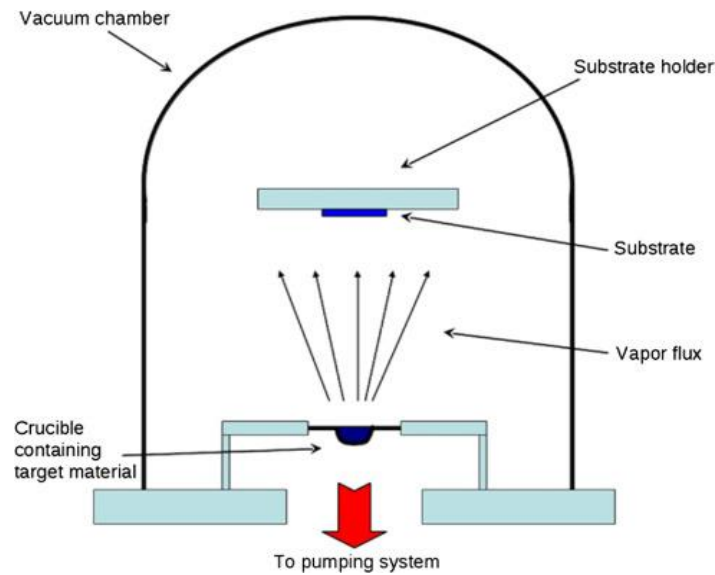


Fig 1.2 Thermal evaporation method

ii. Electron beam evaporation method

Electron beam physical vapor deposition (EBPVD) is a form of physical vapor deposition in which an electron beam emitted from a charged tungsten filament under a high vacuum strikes a target anode. The electron beam moves atoms from the target into the gas phase. These atoms then fall in solid form and into everything in the vacuum chamber with a thin layer of (visible) anode material.

Thin film deposition is a process used in the semiconductor industry to grow electronic materials, in the aerospace industry to form thermal and chemical barrier coatings to protect surfaces from corrosive environments, and in optics to form substrates. is used to impart desirable reflective and transmissive properties to An industry that modifies surfaces to have various desirable properties. Deposition processes can be broadly divided into physical vapor deposition (PVD) and chemical vapor deposition (CVD). In CVD, film growth occurs at high temperatures, which can form corrosive gas products and leave impurities in the film. PVD processes can be run at lower deposition temperatures without corrosive products, but typically at lower deposition rates. However, e-beam physical vapor deposition achieves high

deposition rates of 0.1–100 $\mu\text{m}/\text{min}$ at relatively low substrate temperatures with very high material utilization efficiency.

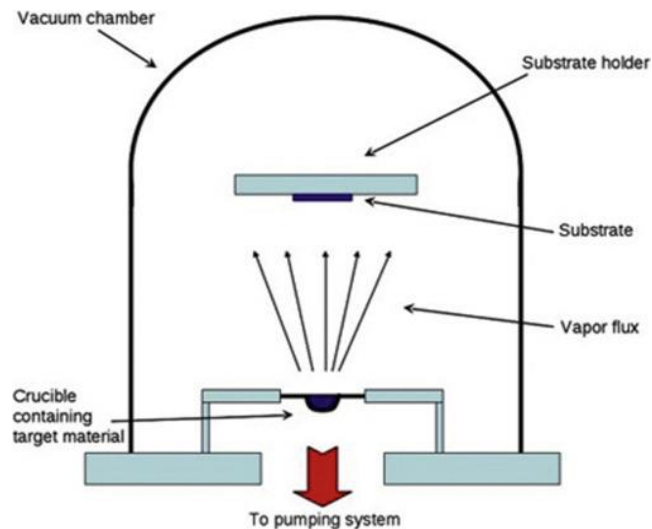


Fig 1.3 Electron beam evaporation method

iii. Molecular beam epitaxy (MBE) method

Molecular Beam Epitaxy (MBE) is an epitaxial process for single crystal thin film deposition. MBE is widely used in the fabrication of semiconductor devices, including transistors, and is recognized as one of the fundamental tools for the advancement of nanotechnology. MBE is used to manufacture diodes and MOSFETs (MOS Field Effect Transistors) at microwave frequencies, and lasers are used to read optical discs (such as CDs and DVDs).

The original idea of the MBE process was first established by Günther. The films he deposited were not epitaxial but deposited on glass substrates. With the development of vacuum technology, Davey and Pankey demonstrated his MBE process and successfully grew his GaAs epitaxial films on single crystal GaAs

substrates using Günther's method. Subsequent significant developments in MBE films were J.R. in his Arthur study of the dynamic behavior of the growth mechanism in the late 1960s and Alfred Y. Cho in his in situ observation of the MBE process using RHEED.

Molecular beam epitaxy is performed at high or ultra-high vacuum (10^{-8} to 10^{-12} Torr). The most important aspect of MBE is the deposition rate (typically less than 3,000 nm per hour) and the ability to grow films epitaxially. These deposition rates require proportionately better vacuums to achieve the same contamination levels as other deposition techniques. Similar to the ultra-high vacuum environment, the absence of carrier gas ensures the highest possible purity of the grown films.

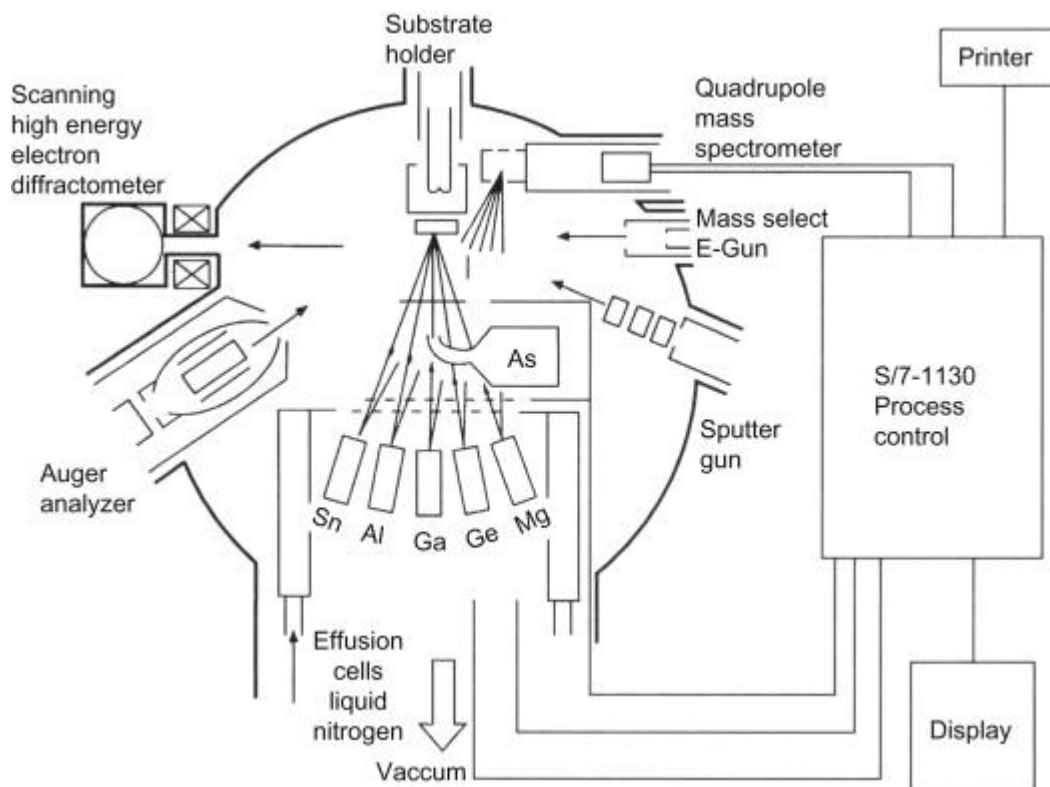


Fig 1.4 Molecular beam epitaxy

iv. *Sputtering*

Sputtering is the process of depositing thin layers onto a substrate in a vacuum chamber. It involves removing atoms or molecules from a target material, usually a metal or semiconductor, and bombarding it with high-energy ions or plasma. These atoms or molecules are then deposited onto a substrate to form a thin film.

The sputtering process can be achieved using various techniques such as B. DC sputtering, HF sputtering, magnetron sputtering, or reactive sputtering. Each technique has its strengths and weaknesses depending on the specific application and needs. DC sputtering is the simplest and most widely used technique in which a high voltage is applied to a cathode made of target material and the resulting plasma discharge ions bombard the target, ejecting atoms or molecules from the surface. RF sputtering is similar but uses radio frequencies instead of DC to generate the plasma.

Sputtering is used in various industries such as electronics, optics, and energy to produce thin films with precise thickness, composition, and properties. They are also used for surface modification such as etching and cleaning, and for creating nanostructures and coatings.

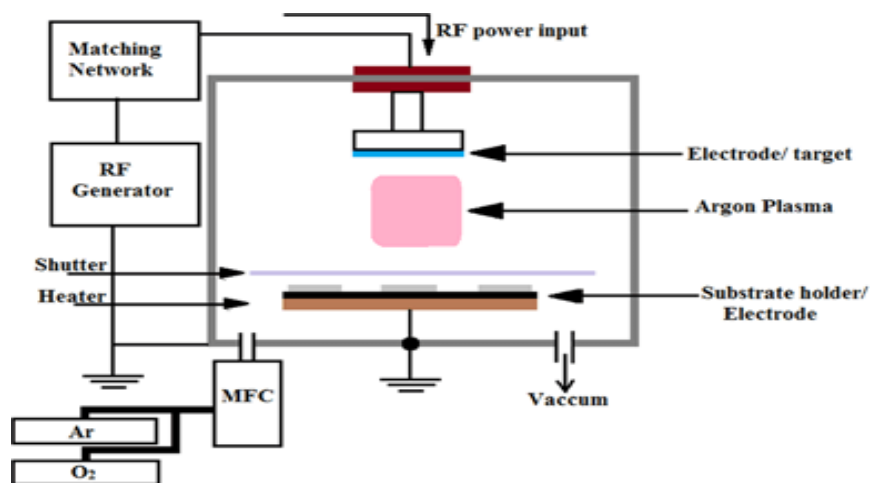


Fig 1.5 Sputtering

1.6.2 CHEMICAL VAPOR DEPOSITION (CVD)

Chemical vapor deposition (CVD) is a process used to deposit thin films of various materials by reacting gaseous precursors onto substrates. In CVD, a substrate is placed in a reactor and a precursor gas or gas mixture is introduced into the reactor chamber. The precursor gas then pyrolyzes or reacts with other gases in the chamber to form a solid film on the substrate. CVD can be used to deposit a wide variety of materials including metals, semiconductors, ceramics, and polymers. This process is widely used in the semiconductor industry to deposit thin films for microelectronic devices such as integrated circuits, thin film transistors, and solar cells. There are various types of CVD processes such as reduced pressure CVD, atmospheric pressure CVD, plasma-enhanced CVD, and photochemical CVD. In low-pressure CVD, precursor gases are introduced into a vacuum chamber at low pressure, typically in the range of 1-100 Pa. Atmospheric pressure CVD operates at atmospheric pressure and typically uses a bubbler system to introduce precursor gases. Plasma-enhanced CVD uses an electric field or plasma to promote the decomposition of precursor gases and promote the formation of a solid film. Photochemical CVD uses light to initiate the decomposition of precursor gas. CVD has several advantages over other deposition methods, including the ability to deposit conformal films with precise control over film thickness and composition. However, this process requires special equipment and can be expensive and time-consuming additionally, the chemical reactions involved in CVD can produce toxic gases, which can make the process hazardous.

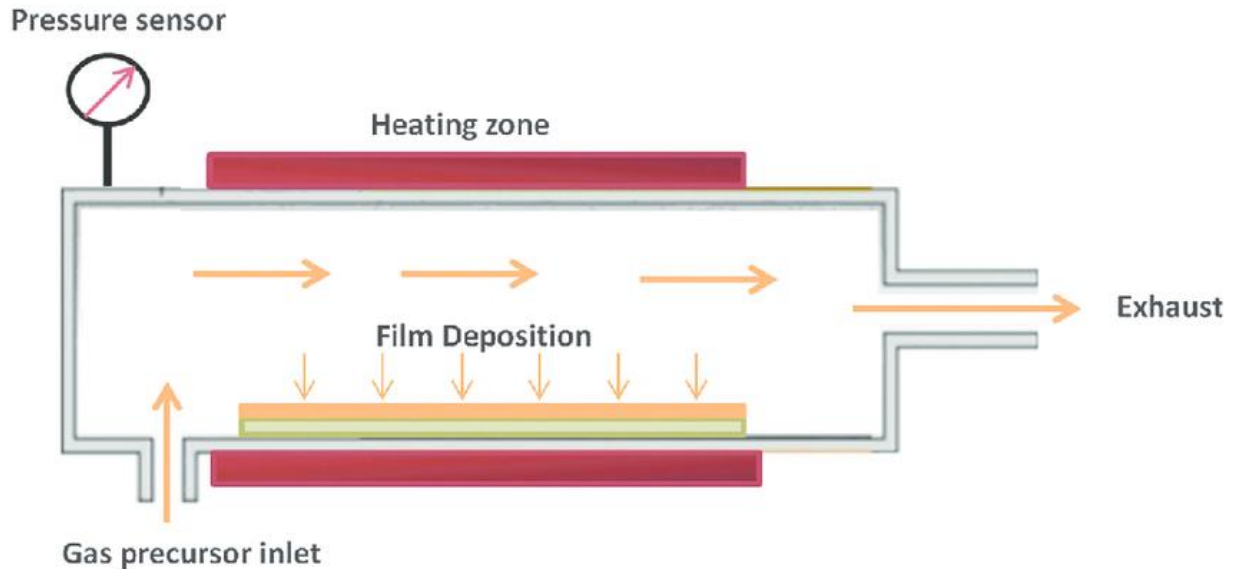


Fig 1.6 Chemical vapor deposition

i. Plasma Enhanced CVD (PECVD) method

Plasma-enhanced chemical vapor deposition (PECVD) is a type of chemical vapor deposition (CVD) that uses plasma to enhance the deposition process. In PECVD, precursor gases are introduced into a reaction chamber where they are exposed to an electric field or plasma. The plasma ionizes the gas and breaks it down into reactive species that can react with the substrate to form a thin film. PECVD is commonly used to deposit thin layers of silicon dioxide (SiO_2) and silicon nitride (Si_3N_4) for microelectronic applications such as integrated circuits and thin film transistors. PECVD can also be used to deposit coatings for optical applications, such as anti-reflection coatings and passivation layers for solar cells. PECVD has several advantages over traditional CVD processes, including lower deposition temperatures, better step coverage, and the ability to deposit high-quality films on a variety of substrates such as plastics and metals. In addition, PECVD can be used to deposit films with high uniformity and precise control of thickness and composition. However, PECVD also has some drawbacks. This process can be

more complex than traditional CVD, requiring special equipment and controlled plasma conditions. Additionally, plasmas can damage delicate substrates, and reactive species generated during the process can pose a hazard to operators if proper safety precautions are not taken.

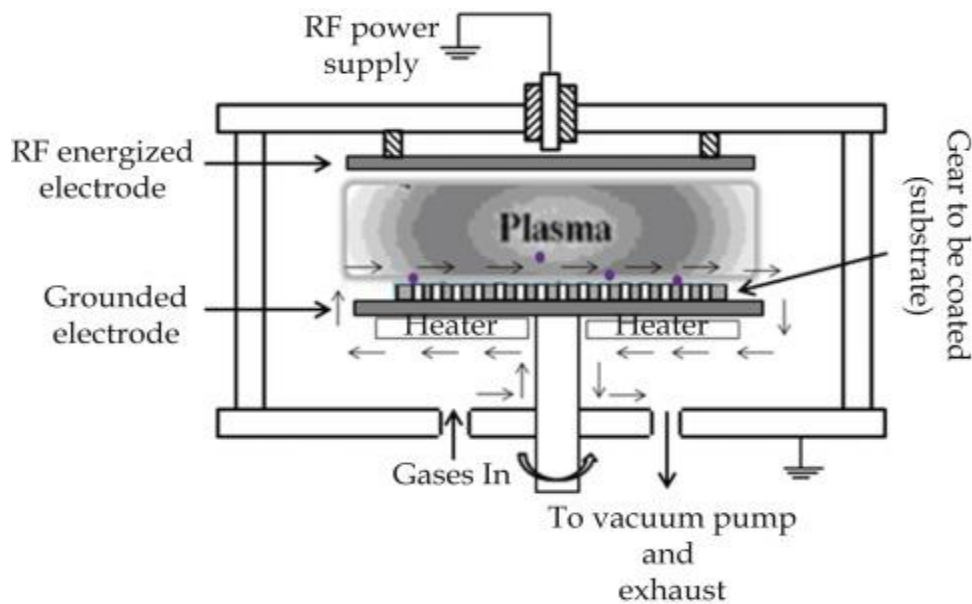


Fig 1.7 Plasma-enhanced CVD method

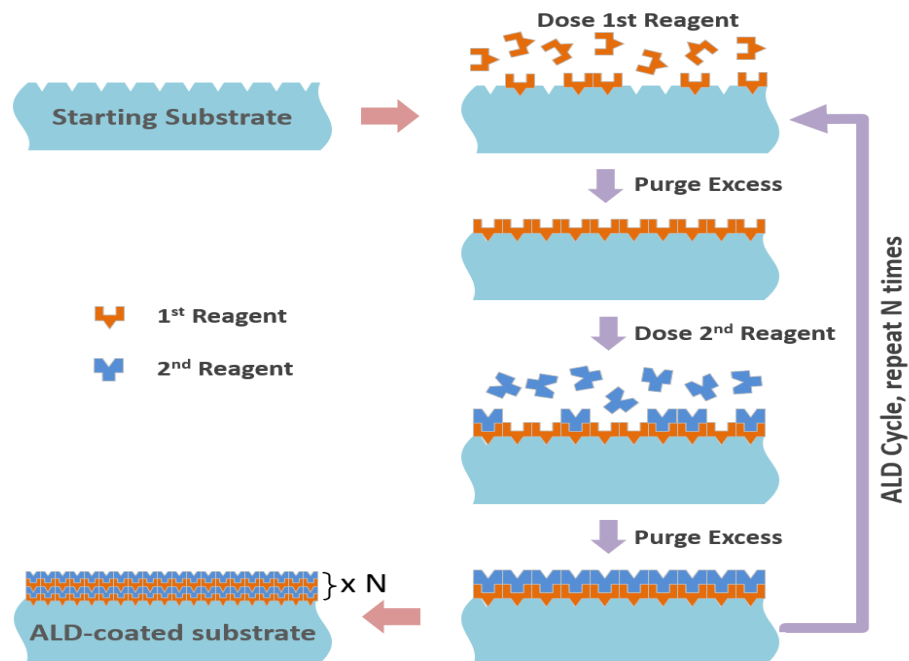
ii. Atomic Layer Deposition (ALD) Method

Atomic layer deposition (ALD) is a thin film deposition technique that enables the growth of high-quality, conformal films with atomically precise thickness control. In ALD, the substrate is exposed to alternating pulses of two or more precursor gases, each of which reacts with the surface of the substrate in a self-limiting manner.

During the deposition process, precursor molecules react with the substrate surface to form a monolayer of material. Excess precursor molecules are then removed, typically by a purge step using an inert gas such as nitrogen. The process is then repeated with a second precursor gas that reacts with the surface to deposit another monolayer of material. ALD allows precise control of film thickness and composition with sub-nanometer precision by alternately exposing

and purging precursor gases. This level of control has made ALD a popular technique for fabricating ultra-thin films and complex-shaped nanoscale devices. ALD is used in a variety of applications including microelectronics, energy storage, catalysis, and biomedical devices. ALD is also used to deposit various materials such as metals, oxides, nitrides, and sulfides.

ALD has many advantages over other thin film deposition techniques. One of the main advantages is the ability to deposit high-quality films with precise control over thickness and composition. ALD can also be used to deposit films on a variety of substrates, including metals, semiconductors, and insulators. ALD is widely used to manufacture semiconductor devices such as transistors, capacitors, and memory cells, as well as advanced coatings for applications such as solar cells, fuel cells, and biomedical devices.



1.8 atomic layer deposition method

1.6.3 SOL GEL TECHNIQUE

Sol-gel technology is a versatile method for producing thin films with different chemical compositions and physical properties. In this process, a sol, a colloidal suspension of solid particles in a liquid, is transformed into a solid film.

1. The steps of the sol-gel thin film fabrication process are Sol preparation: The starting material, typically a metal alkoxide, is dissolved in a suitable solvent such as alcohol or water. The solution is then stirred and aged to form a stable sol.
2. Sol deposition: The sol is then deposited onto the substrate using methods such as spin coating, dip coating, or spray coating. Substrates can be made from a variety of materials, including glass, silicon, and plastic. Gelling: The deposited sol is transformed into a gel by chemical or physical processes.
3. In chemical gelation, a cross-linking agent is added to the sol to induce the formation of a three-dimensional particle network. Physical gelation removes the solvent and causes particles within the sol to assemble to form a firm gel. Drying and Annealing.
4. The gel is then dried and annealed at high temperatures to remove the solvent and promote the formation of the final thin film. Annealing temperature and time depend on the film composition and desired properties.

The sol-gel method offers several advantages over other thin film fabrication methods, such as the ability to control film composition and morphology, the ability to fabricate films on a variety of substrates, and the potential for low-cost production. Sol-gel films are used in a variety of applications including coatings, sensors, electronic devices, and biomedical implants.

1.6.4 SPRAY PYROLYSIS TECHNIQUE

Spray pyrolysis technology is a process that produces thin films of various materials such as oxides, sulfides, and metals. In this process, a precursor solution is deposited on a heated substrate and then pyrolyzed to form a thin film.

The steps of the atomization pyrolysis thin film manufacturing process are as follows: Precursor Solution Preparation.

1. A starting material, usually a metal salt or organometallic compound, is dissolved in a suitable solvent to form a precursor solution. The solution is then stirred and aged to form a stable solution.
2. Precursor Solution Deposition: Next, the precursor solution is atomized into small droplets using an atomizing nozzle and directed onto the heated substrate. Substrates can be made of a variety of materials, including glass, silicon, and metals.
3. Pyrolysis: The droplets on the substrate undergo pyrolysis to form a thin film. The pyrolysis process involves the decomposition of precursor molecules and the formation of a solid film. The film thickness and composition depend on the precursor solution concentration, deposition time, and substrate temperature.
4. Annealing: The thin film is then annealed at high temperatures to improve crystallinity and remove residual solvents or organic materials.

Spray pyrolysis technology offers several advantages over other thin film fabrication methods, such as the ability to produce films with large areas and complex geometries, low cost, and ease of handling. Atomized pyrolysis films are used in a variety of applications, including photovoltaics, sensors, and catalysts. However, film quality and uniformity can be affected by several factors, including precursor solution quality, spraying conditions, and substrate properties.

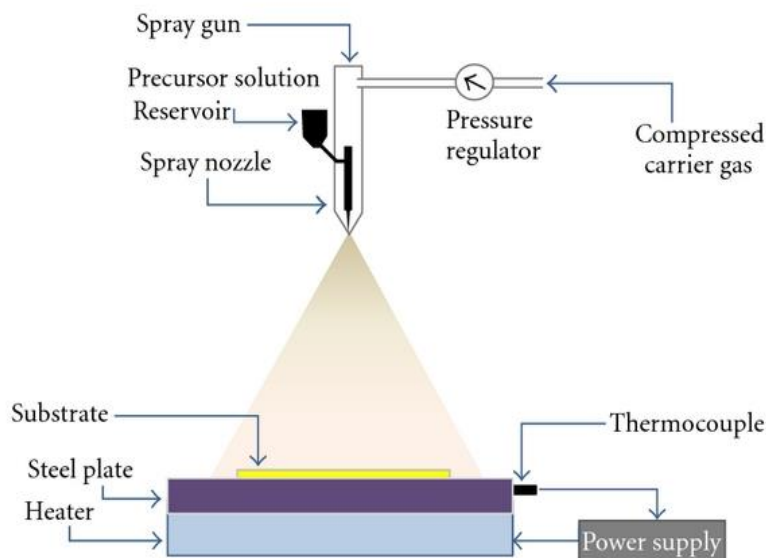


Fig 1.9 Spray pyrolysis technique

1.6.5 SPIN COATING TECHNIQUE

Spin coating is a commonly used technique for depositing thin films on substrates. A solution or suspension of the desired material is spun onto the substrate at high speed, typically thousands of revolutions per minute (RPM). During the spin-coating process, the centrifugal force generated by the spin spreads the liquid evenly over the substrate to form a thin film.

The film thickness can be controlled by adjusting the solution or suspension concentration, spin speed, and spin time. Spin coating is widely used in various fields such as microelectronics, optics, and nanotechnology due to its simplicity, versatility, and ability to produce high-quality thin films. This process can be performed on a wide range of materials including polymers, metals, ceramics, and semiconductors. However, the spin ing has some limitations, such as the difficulty of controlling the film thickness at the edge of the substrate and the potential for defects and cracks in the film during the drying process. Despite these limitations,

spin coating remains a popular and effective method for producing thin films for a variety of applications.

This process typically includes the following steps:

1. **Solution or Suspension Preparation:** Dissolve or suspend the material to be deposited in a suitable solvent to form a solution or suspension. Solution viscosity and concentration are important parameters that affect the final thickness and uniformity of the film.
2. **Solution Application:** Solutions are dispensed onto substrates placed on a rotating platform. The amount of solution applied and the spin speed is important parameters that affect the final thickness and uniformity of the film.
3. **Spinning:** The spinning platform rotates at high speed, typically in the range of thousands to tens of thousands of revolutions per minute, to spread the solution across the surface of the substrate and form a thin film. The centrifugal force generated by the spinning action helps spread the solution evenly over the substrate.
4. **Drying:** After the spin cycle, the substrate is typically heat or air-dried. This causes the solvent to evaporate, leaving behind a thin film of material

Spin coating is a simple and versatile technique that can be used to deposit a wide variety of materials including polymers, metals, ceramics, and semiconductors. It is commonly used in the manufacture of microelectronic devices, optical coatings, and other thin film applications.

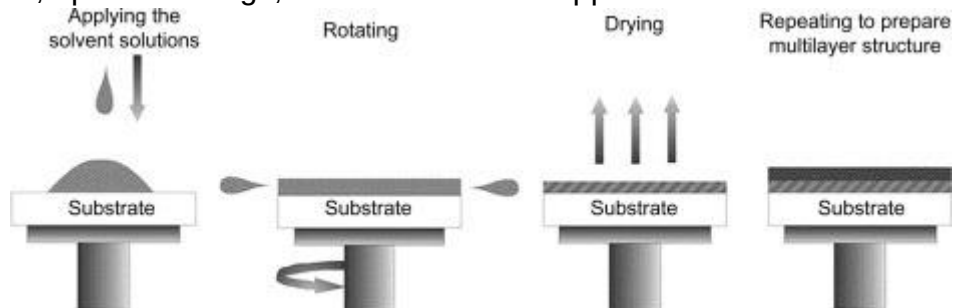


Fig 1.10 Spin coating technique

1.6.6 DIP COATING TECHNIQUE

Dip coating is a technique used to deposit a thin film onto a substrate by immersing the substrate in a solution containing precursor materials for the desired film.

This process involves several steps.

1. Substrate preparation: The substrate is first thoroughly cleaned to remove impurities and contaminants that can affect film adhesion and quality.
2. Solution Preparation: Solutions are prepared by dissolving the precursor material in a solvent such as water or an organic solvent. Solution concentration and composition are carefully controlled to ensure the desired film properties. Substrate immersion: The substrate is then immersed in the solution. Carefully control the immersion time to ensure uniform coating thickness.
3. Substrate withdrawal: The substrate is slowly withdrawn from the solution at a constant rate. This allows an excess solution to drip off, forming a film on the substrate surface.
4. Drying and Curing: The coated substrate is then dried and cured at a specific temperature and time to transform the precursor material into the desired film.

Dip-coating techniques are simple, inexpensive, and can produce high-quality thin films in a wide range of thicknesses, from a few nanometers to a few microns. However, there are some limitations such as B.'s Inability to deposit films on complex three-dimensional substrates and limited control over film composition and structure.

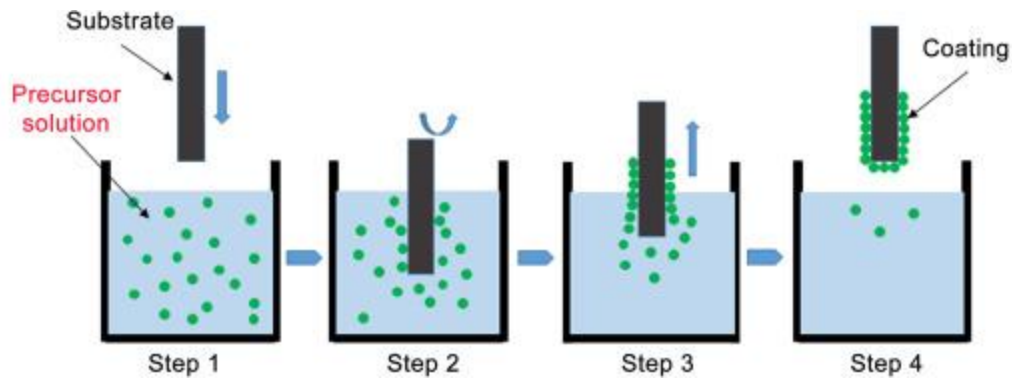


Fig 1.11 Dip coating method

1.7 RECENT RESEARCH IN SOLAR CELLS

Solar cells, additionally called photovoltaic cells, are gadgets that convert daylight into electric power. They are a promising generation for sustainable power manufacturing and feature visible substantial studies in the latest years to enhance their performance, sturdiness, and cost-effectiveness. Here are a few latest trends in sun molecular studies.

1. perovskite sun cells: Perovskite substances have proven top-notch capacity in sun molecular generation because of their excessive performance and occasional cost. Recent studies have targeted enhancing the stableness and sturdiness of perovskite solar cells, in addition to growing scalable production techniques.
2. Tandem sun cells: Tandem sun cells are a sort of multi-junction sun molecular that stack more than one layer of solar cells to grow performance. Recent studies have targeted growing new substances and designs for tandem sun cells to similar growth in their performance.
3. Silicon heterojunction sun cells: Silicon heterojunction sun cells are a sort of sun molecular that makes use of a mixture of amorphous and crystalline silicon

layers to enhance performance. Recent studies have targeted growing new production strategies and enhancing the overall performance of those cells.

4. sun cells: Organic sun cells are a sort of sun molecular that makes use of natural substances because of the energetic layer. Recent studies have targeted growing new substances and enhancing the performance and balance of natural sun cells.
5. Solar Mobile Device Recycling: As the number of solar panel installations increases, there is a growing need for recycling methods to recover more valuable materials and reduce waste.

Recent research is focused on developing cost-effective and environmentally friendly methods for recycling solar cells. In general, research on solar mobile devices aims to improve the performance, reliability, and cost-effectiveness of solar cells, making them a cheaper and more sustainable energy source in the future.

Areas of Focus

Thin films have a huge variety of packages and study regions. These regions of recognition can include, however, aren't restricted to, the deposition and characterization of thin films, the improvement of thin film deposition strategies, the evaluation of thin film systems, and the advent of thin films primarily based totally merchandise.

Deposition and characterization of thin films include the increase and manipulation of thin films to gain favored houses and systems. Several strategies, together with chemical vapor deposition, bodily vapor deposition, sputtering, and electroplating are used for the deposition of thin film.

Characterization of thin films consists of the dedication to composition, thickness, floor topography, and electrical, optical, and mechanical houses. The improvement of thin film deposition strategies is a vital place of study and includes

the development of current strategies, in addition to the improvement of recent strategies.

This painting can cause the improvement of recent tactics that may be used withinside the fabrication of thin films primarily based totally merchandise. The evaluation of thin film systems is another vital place of study. This includes the usage of strategies together with X-ray diffraction, transmission electron microscopy, and scanning electron microscopy to observe the shape and houses of thin films.

The advent of thin film primarily based totally merchandise is a vital place of study and includes the improvement of recent materials, the optimization of current materials, and the improvement of tactics that may be used withinside the fabrication of thin film primarily based totally merchandise. These photos are of luxury homes and may lead to recent product improvements.

Thin film is a very promising generation in the field of solar cells. Recent studies have sought to discover new, progressive methods for creating thin films that can be used to fabricate solar cells.

One of the main dreams of this research is to increase the efficiency of solar cells that use thin films that are thinner and better able to absorb and convert daylight into electricity.

Recent studies in thin films have focused on using nanotechnology to create thin films that are both thinner and stronger than conventional materials. This form of nanotechnology has enabled the use of very thin films that can absorb a softer spectrum than conventional materials, leading to higher efficiency in solar cells.

Researchers have also figured out how to combine certain types of low-fat films to create greener solar cells. Another area of recent research has focused on using nanostructures to similarly improve the performance of solar cells. Nanostructures

are microscopic systems that can be used to create very thin films that can better absorb and convert light.

This research has made solar panels greener than ever before. Finally, studies using thin films have been conducted to increase the electrical resistance of solar cells. This type of research has led to solar cells that are more resistant to corrosion and wear, making them more durable and reliable.

Overall, thin-film research has led to many advances in making solar cells greener, more durable, and more reliable. This form of research will still be important in the solar cell field as it can help make solar energy greener and more economical in the future. Thin films have a wide variety of packages and research areas, and research in these areas can lead to improvements in newer materials, tactics, and products.

CHAPTER 2

LITERATURE SURVEY

1. N. Khademi, Bi-Doped SnO₂ Transparent Conducting Thin Films Deposited By Spray Pyrolysis: Structural, Electrical, Optical And Photo-Thermoelectric Properties, In this exploration, light and weighty Bi-doped SnO₂ meager films were ready on glass substrates by shower pyrolysis process–gel he impact of weighty doped-Bi on the primary, morphological, electrical, photograph thermo-electrical, and optical properties of SnO₂ films has been examined.
2. Sandeep Arya, Mohammad Riyas, Electrochemical detection of ammonia solution using tin oxide nanoparticles synthesized via sol–gel route, Usolnanoparticless of tin oxide (SnO₂) synthesized in sol–gel, electrochemical detection of ammonia solution (NH₄OH) is the subject of this investigation. Underlying qualities were concentrated on utilizing X-beam diffraction, examining electron magnifying instruments, and energy-dispersive X-beam spectroscopy that affirmed the development of tin oxide nanoparticles. Optical portrayals were additionally contemplated using UV-Vis-IR spectroscopy and photoluminescence spectroscopy.
3. S. S. Soumya, Conductivity type inversion and optical properties of aluminum doped SnO₂ thin films prepared by sol-gel spin coating technique, The structural, optical, and electrical properties of sol-gel spin-coated aluminium doped tin oxide thin films are discussed in this paper. The XRD measurements confirmed that SnO₂ has a tetragonal rutile structure with a preference for orientation along the (1 1 0) plane.
4. P. A. Savale, Physical Vapor Deposition (PVD) Methods for Synthesis of Thin Films: A Comparative Study, The most significant physical vapor deposition techniques for thin films, namely, Activated reactive evaporation, thermal evaporation, electron beam evaporation, molecular beam epitaxy evaporation, ion plating, and pulsed laser deposition were all investigated.
5. Harish Sharma Akkera, Studies of the effect of Bi-doped on structural, electrical, and optical properties of spin-coated SnO₂ transparent conducting oxide thin films,

We made SnO₂ with different concentrations of Bi-doped SnO₂ (Bi: 1, 2, 3, 4, and 5%). SnO₂) thin films through the use of sol-gel spin coating. All of the deposited films have a polycrystalline tetragonal rutile structure, as demonstrated by X-ray diffraction studies. The Raman modes Eg, A1g, and B2g are represented by three fundamental spectra at 473, 631, and 774 cm⁻¹, respectively. All deposited films' average transmittance was measured.

6. D. Trejo-Zamudio, Structural and thermoelectric properties of SnO₂:Bi thin films, The structural and thermoelectric properties of SnO₂ and SnO₂ thin films were prepared and studied in this work: Bi are accounted for. The spray pyrolysis method was used to deposit both doped and undoped films at 400 °C. The XRD portrayal shows disintegration in the glasslike nature of the examples when how much dopant increments. When there is more dopant (Bi) in the samples, the size of the crystallites shrinks. In the material's lattice, the Bi³⁺ ion took the place of the Sn⁴⁺ ion. This diminishes the centralization of charge transporters however keeps up with n-type conductivity
7. Hai-Hong Wu, Preparation and Characterization of Bismuth Doped TiO₂ Thin Films, The sol-gel dip coating process was used to create several bismuth-doped titanium oxides (Bi-doped TiO₂) thin films on glass substrates. XRD and XPS were used to characterize the prepared catalysts. The photodegradation of aqueous methyl orange under UV illumination was used to measure the photocatalytic activity of the thin film catalysts. The anatase phase of the prepared Bi-doped TiO₂ was demonstrated by the experiments. The doped bismuth was in the 3p oxidation state

CHAPTER 3

AIM AND SCOPE

3.1 AIM

We aim to synthesize the bismuth-doped and undoped SnO₂ thin film to analyze the characteristics of the film. We aimed the synthesis through non-conducting materials coated over a substrate which is also a non-conducting material. The synthesis is mainly focused on solar cell applications. We choose the dip coating technique since using the method to become very difficult to synthesize the SnO₂ thin films. As a challenge of our work, we optimize the technique and we plan to synthesize the SnO₂ thin films.

3.2 SCOPE

SnO₂ thin film has a wide range of applications in solar cells, offering high performance, low cost, and low environmental impact. SnO₂ thin film has a unique combination of properties, such as high electrical conductivity, good optical transparency, a wide range of light absorption, and thermal stability, which makes it an ideal material in photovoltaic applications.

SnO₂ thin film has a wide range of applications in the solar cell industry, such as in back contacting, transparent conducting layers, and antireflection coating. In back contacting, SnO₂ thin film helps to reduce the recombination rate and increase cell efficiency. In transparent conducting layers, SnO₂ thin film provides good optical transparency and electrical conductivity. The antireflection coating based on SnO₂ thin film helps to reduce the light reflection and improve the light absorption of the solar cell.

In conclusion, SnO₂ thin film has a wide range of applications in solar cells, from back contacting to buffer layers. Its unique combination of properties makes it an ideal material to improve the performance of solar cells.

CHAPTER 4

MATERIALS AND METHODOLOGY

4.1 MATERIALS

Stannous chloride dehydrate

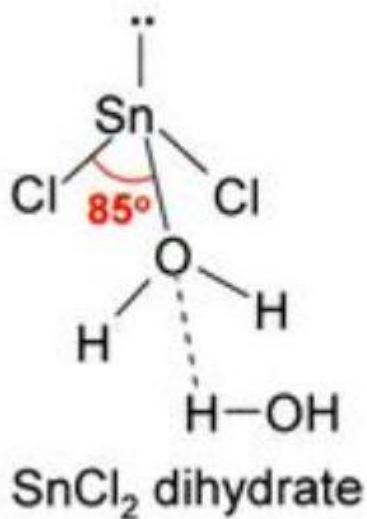


Fig 4.1 Structure of stannous chloride dihydrate

Chemical name : stannous chloride dehydrate

Systematic name : Tin(II) chloride

Molecular formula : SnCl₂·2H₂O

Molar mass : 225.6 g/mol

Melting point : 246 °C (519 K)

Boiling point : 623 °C (896 K)

Density : 2.71 g/cm³

Soluble In : ethanol, diethyl ether, acetic acid, acetone

Solubility in water : 83.9 g/100 ml (0 °C) Hydrolyses in hot water

Stannous chloride dihydrate is a chemical compound with the formula $\text{SnCl}_2 \cdot 2\text{H}_2\text{O}$. It is a white crystalline solid that is soluble in water and alcohol. The compound is also known as tin(II) chloride dihydrate or tin dichloride dihydrate.

Stannous chloride dihydrate is used in various industrial processes, including electroplating, dyeing, and printing. It is also used as a reducing agent in chemical reactions and as a catalyst in organic synthesis. Additionally, it is used in analytical chemistry to detect the presence of gold, mercury, and arsenic in various samples.

However, stannous chloride dihydrate is a hazardous substance, and exposure to it can be harmful. It can cause skin and eye irritation, and prolonged exposure can lead to lung damage. Therefore, it should be handled with care and only by trained professionals who are familiar with its properties and safety measures.

ETHANOL

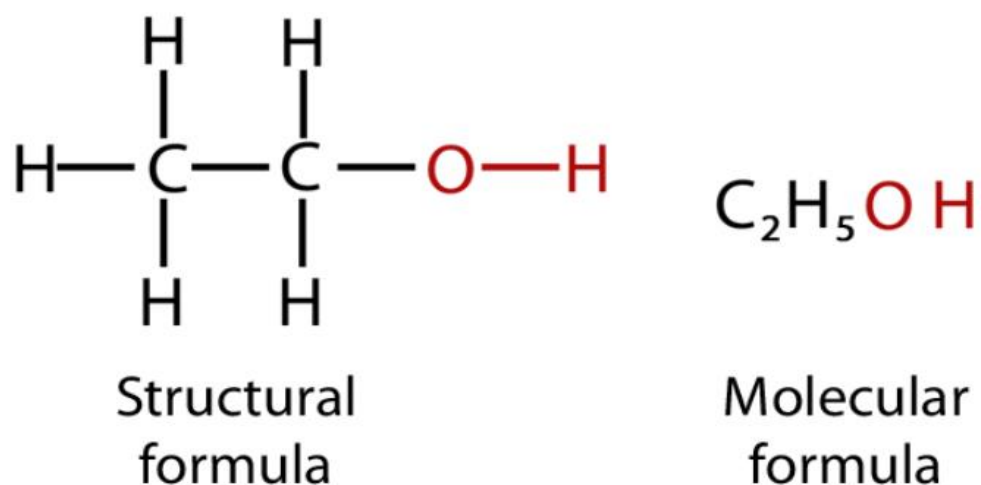


Fig 4.2 Structure of ethanol

Chemical name	: Ethyl alcohol
Systematic name	: Ethanol
Molecular formula	: C ₂ H ₆ O
Molar mass	: 46.069 g/mol
Melting point	: 114.14 ± 0.03°C (159.01 ± 0.03 K)
Boiling point	: 78.23 ± 0.09°C (351.38 ± 0.09 K)
Density	: 0.78945 g/cm ³
Solubility in water	: Miscible

Ethanol is a colorless, flammable, and volatile chemical compound with the chemical formula C₂H₅OH. It is a type of alcohol that is commonly used as a fuel, solvent, and disinfectant. Ethanol is produced by the fermentation of sugars, typically from corn or sugarcane, and is also a byproduct of the petroleum refining process.

Ethanol is widely used as a biofuel in gasoline blends, especially in countries where ethanol production is subsidized or mandated by government policy. It is also used as a solvent in the production of various consumer products, including cosmetics, pharmaceuticals, and personal care items. In addition, ethanol is a common ingredient in alcoholic beverages such as beer, wine, and spirits.

While ethanol has many uses, it is important to handle it with care, as it is highly flammable and can be dangerous if ingested in large quantities. In addition, ethanol can have negative impacts on the environment, including increased greenhouse gas emissions and potential contamination of water sources if spilled or leaked.

BISMUTH NITRATE

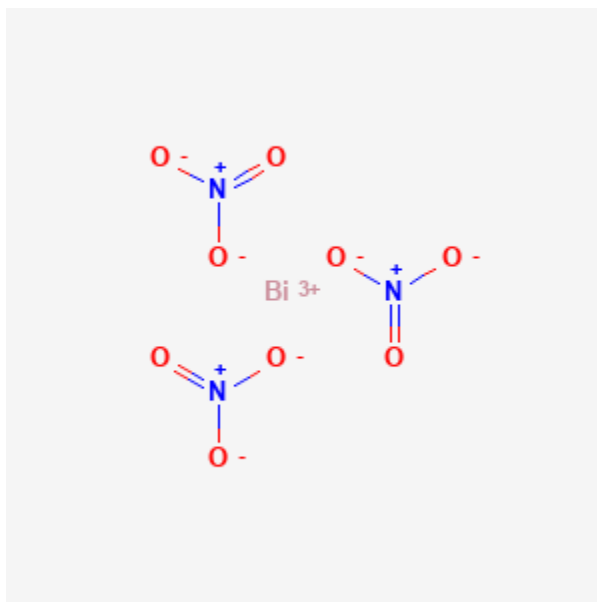


Fig 4.3 Structure of Bismuth Nitrate

Chemical name	: Bismuth nitrate
Systematic name	: Bismuth trinitrate
Molecular formula	: $\text{Bi}(\text{NO}_3)_3$
Molar mass	: 394.99 g/mol
Boiling point	: 75-80 °C (lit.)
Melting point	: 30 °C (lit.)
Density	: 2.90 g/cm ³
Solubility	: Slightly soluble in acids

Bismuth trinitrate is a chemical compound with the formula $\text{Bi}(\text{NO}_3)_3$. It is a white or yellow crystalline solid that is soluble in water and other polar solvents. Bismuth trinitrate is used in the synthesis of other bismuth compounds, as a reagent in analytical chemistry, and as a component in some pyrotechnic compositions.

In addition to its use in chemistry and pyrotechnics, bismuth trinitrate also has medical applications. It has been used in the treatment of diarrhea, as it can help to slow down intestinal motility. Bismuth trinitrate is also used as a contrast agent in X-ray imaging, as it has a high atomic number and can help to increase the contrast between different tissues and structures in the body.

However, it is important to handle bismuth trinitrate with care, as it is toxic and can cause skin irritation, eye damage, and respiratory problems if inhaled or ingested. Proper protective equipment, such as gloves and goggles, should be worn when working with bismuth trinitrate

Bismuth trinitrate is used in various chemical processes, including the production of bismuth oxide, as a catalyst in certain reactions, and as a reagent in the synthesis of other compounds. It is also used in some pyrotechnic compositions to produce a green flame.

Like other nitrates, bismuth trinitrate is potentially explosive and should be handled with care. It is important to follow proper safety protocols and use appropriate protective equipment when working with this compound.

4.2 METHODOLOGY

4.2.1 DIP COATING PRINCIPLE

Dip coating is a simple and effective technique widely used in manufacturing in various industries. During research and development, it has become a key coating process for producing thin layers using dedicated dip coaters. If the process is optimized, dip coating can produce very uniform films. Importantly, critical factors such as film thickness can be easily controlled.

4.2.2 DIP COATING PROCESS DESCRIPTION

Substrate cleaning:

The substrate will take in glass and it will be washed with the isopropyl alcohol and then rinsed several times in the distilled water. The glass was then cleaned with the ethanol and then it will be dried for 10mins.

Dip coating process explanation

Dip coating generally involves the application of thin films. In this process, the prepared solution is coated on the surface of the glass substrate. The steps involved in the coating of the films are explained as follows.

Steps involved in the dip coating technique

Cleaning the substrate: The substrate, typically a flat or curved surface made of glass, metal, or plastic, is first cleaned to remove any contaminants and ensure a uniform surface.

Preparing the solution: A solution of the desired material is prepared, typically by dissolving the material in a solvent. The viscosity and concentration of the solution are important parameters that can affect the thickness and uniformity of the film.

Immersing the substrate: The substrate is immersed in the solution at a controlled speed, typically using a dip coater or similar apparatus. The immersion time and withdrawal speed are critical parameters that determine the thickness and quality of the deposited film.

Drying and curing: After the substrate is withdrawn from the solution, an excess solvent is allowed to evaporate, leaving behind a thin film on the substrate. The film is then dried and cured, typically by heating it to a specific temperature for a specified time, to promote adhesion and improve film properties.

The dip coating process is widely used in a variety of industries including microelectronics, optical coatings, and biomedical devices due to its simplicity, low cost, and ability to deposit uniform thin films on a variety of substrates. The film thickness can be adjusted by adjusting the solution concentration and soaking time, and the film properties can be further optimized by changing the drying and curing conditions.

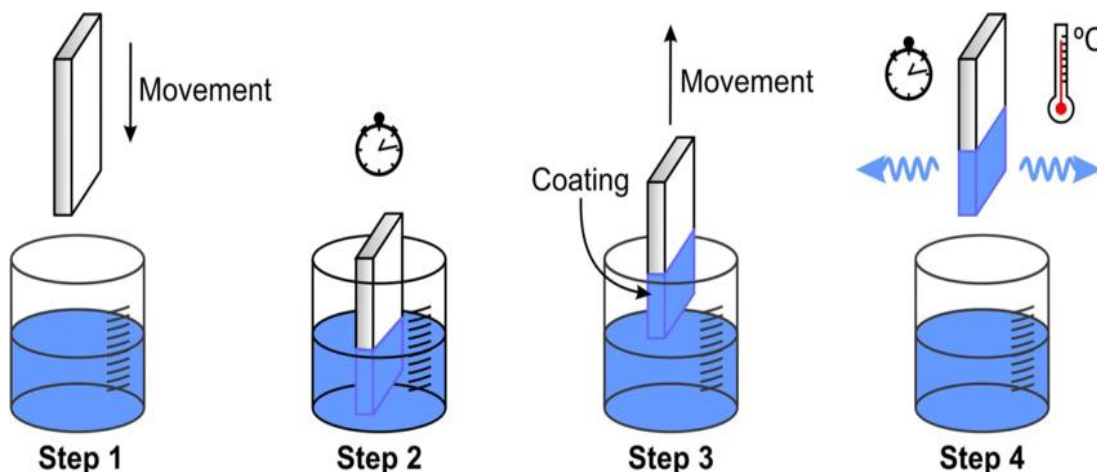


Fig 4.4 Dip coating process

Dip coating Duration

The cleaned glass substrate is gently immersed in the solution and it will be kept inside the solution for a dip coating duration of 30 seconds. The substrate is kept inside for the film formation on the surface of the glass substrate. After that time, the substrate is taken and then kept outside for drying the film on the surface of the substrate. The process is repeated to increase the thickness of the film.

4.3 DIP COATING APPLICATIONS

Dip coating is a versatile method for depositing thin films onto a substrate. The process involves immersing a substrate into a solution containing the material to be deposited, and then withdrawing it at a controlled rate to form a thin, uniform coating. Here are some common applications of dip coating for thin film deposition:

1. Anti-reflection coatings: Dip coating can be used to deposit thin films onto glass or plastic surfaces to reduce reflection and improve optical performance. Anti-reflection coatings can be useful in applications such as eyeglasses, camera lenses, and solar panels.
2. Corrosion-resistant coatings: Dip coating can be used to deposit thin films of materials such as zinc, aluminum, or chrome onto metal substrates to provide corrosion resistance. This can be useful in applications such as automotive parts, pipelines, and building materials.
3. Protective coatings: Dip coating can be used to deposit thin films of materials such as silicon dioxide or titanium dioxide onto substrates to protect against wear, scratches, or chemical attack. This can be useful in applications such as electronics, optical devices, and industrial equipment.
4. Energy storage: Dip coating can be used to deposit thin films of materials such as lithium cobalt oxide or nickel-cobalt-aluminum onto substrates to make electrodes for energy storage devices such as batteries or supercapacitors. This

can be useful in applications such as electric vehicles, portable electronics, and renewable energy storage.

5. Biomedical applications: Dip coating can be used to deposit thin films of materials such as hydroxyapatite or titanium onto biomedical implants or devices to improve biocompatibility or promote bone growth. This can be useful in dental implants, joint replacements, and tissue engineering applications.

Overall, dip coating is a useful technique for depositing thin films onto a wide variety of substrates, and has many applications in industry, technology, and healthcare.

4.4 ADVANTAGES AND DISADVANTAGES OF DIP COATING

Advantages of dip coating for thin film deposition include:

1. Versatility: Dip coating can be used to deposit a wide range of materials onto a variety of substrates, including glass, plastic, metal, and ceramic.
2. Uniformity: Dip coating can produce a uniform, thin film that covers the entire substrate surface, even on complex shapes or contours.
3. Cost-effective: Dip coating is a relatively simple and low-cost method for depositing thin films, and does not require expensive equipment or facilities.
4. Scalability: Dip coating can be easily scaled up or down to accommodate different batch sizes, making it suitable for both research and large-scale production.
5. Control: Dip coating allows for precise control over the thickness and composition of the deposited film, which can be adjusted by varying parameters such as immersion time, withdrawal speed, and solution concentration.

Disadvantages of dip coating for thin film deposition include:

1. Limited thickness: Dip coating is typically used for depositing thin films up to a few microns thick, and may not be suitable for thicker coatings.

2. Solvent use: Dip coating requires the use of solvents, which can be hazardous or environmentally damaging if not handled properly.
3. Homogeneity: The homogeneity of the deposited film may be affected by factors such as the viscosity of the solution, the speed of withdrawal, and the surface tension of the substrate.
4. Adhesion: The adhesion of the deposited film to the substrate may be affected by factors such as surface cleanliness, surface energy, and film-substrate compatibility.
5. Reproducibility: The reproducibility of the dip coating process may be affected by variations in parameters such as solution concentration, temperature, and humidity, and may require careful optimization to achieve consistent results.

4.5 EXPERIMENTAL PROCEDURE OF UNDOPED SnO_2 THIN FILM

Initially, stannous chloride dihydrate (4.515g) was dissolved in 20 ml of ethanol for making the inhomogeneous solution. This inhomogeneous solution is stirred for 1hr by using a magnetic stirrer. The stirred solution is kept for an aging of 24hrs. After the aging is done a clear homogeneous solution is formed. In this homogeneous solution, the glass substrate is coated by the dip coating method. Finally, the thin film formed on the glass substrate is annealed at 120°C for 3mins. The flow chart of the undoped SnO_2 thin film is shown in Fig 3.5

4.8 EXPERIMENTAL PROCEDURE OF BISMUTH DOPED SnO_2 THIN FILM

Stannous chloride dihydrate (4.515g) mixed with bismuth nitrate 5%, 10%, and 15% was dissolved with 20 ml of ethanol. Then a few drops of conc. HCL was added to this solution. Then, the inhomogeneous solution is stirred by using a magnetic stirrer. This solution is kept for the aging of 24hrs. Then the homogeneous solution can be obtained. In this homogeneous solution, the glass substrate is coated by the dip coating method. Finally, the coated thin film on the surface of the substrate is annealed at 120°C for 30mins. The flow chart for bismuth-doped SnO_2 is shown in Fig 3.6

Fig 4.5 Flow chart of undoped SnO₂ thin film

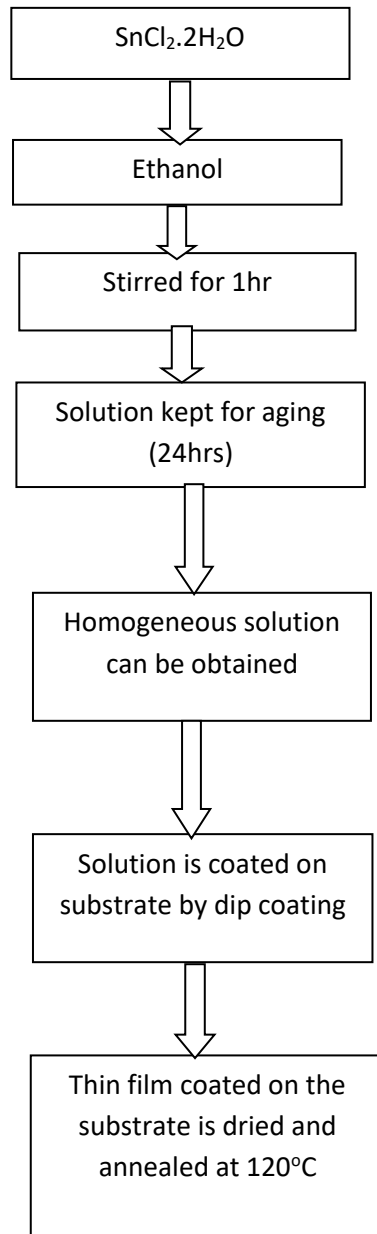
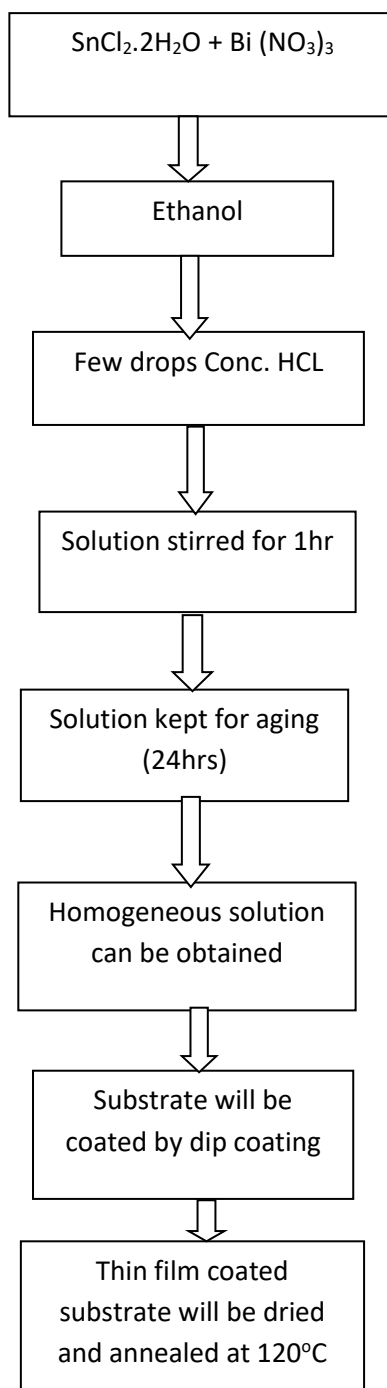


Fig 4.6 Flow chart of bismuth-doped SnO₂ thin film



CHAPTER 5

RESULT AND DISCUSSION

5.1 UV-VIS SPECTROSCOPY

5.1.1 PRINCIPLE

The principle behind UV-Vis spectroscopy is the measurement of the absorption or transmission of light in the ultraviolet and visible regions of the electromagnetic spectrum by a sample.

UV-Vis spectroscopy is based on the Beer-Lambert Law, which states that the concentration of a compound in a solution is directly proportional to the absorbance of light at a specific wavelength. The relationship between absorbance and concentration is described by the equation $A = \epsilon bc$, where A is the absorbance, ϵ is the molar absorptivity (a measure of how strongly a compound absorbs light at a particular wavelength), b is the path length of the sample, and c is the concentration of the compound in solution.

In UV-Vis spectroscopy, a beam of light is directed through a sample, and the amount of light absorbed by the sample is measured using a detector. The intensity of the light transmitted through the sample is compared to the intensity of the incident light, and the absorbance is calculated using the Beer-Lambert Law.

UV-Vis spectroscopy can be used to determine the concentration of a compound in a solution or to study electronic transitions in molecules. It is widely used in many fields, including chemistry, biochemistry, and materials science, due to its simplicity, sensitivity, and versatility.

5.1.2 INSTRUMENTATION AND WORKING OF UV SPECTROSCOPY

The basic instrumentation of UV-Vis spectroscopy consists of a light source, a sample holder, a monochromator, a detector, and a readout device.

1. *Light source:* A UV-Vis spectrophotometer typically uses a tungsten-halogen lamp or deuterium lamp as a light source. The deuterium lamp provides light in the UV region, while the tungsten-halogen lamp provides light in the visible region.
2. *Sample holder:* The sample holder is a cuvette that holds the sample solution. The cuvette is typically made of glass or quartz and has two parallel sides that allow the light to pass through the solution.
3. *Monochromator:* The monochromator is used to isolate a specific wavelength of light from the light source. It consists of a diffraction grating or prism that separates the white light into its component wavelengths.
4. *Detector:* The detector measures the intensity of light that passes through the sample. The most commonly used detectors are photomultiplier tubes (PMT) or charge-coupled devices (CCD).
5. *Readout device:* The readout device displays the absorption or transmission spectrum of the sample. The spectrum can be displayed as a graph of absorbance or transmission versus wavelength.

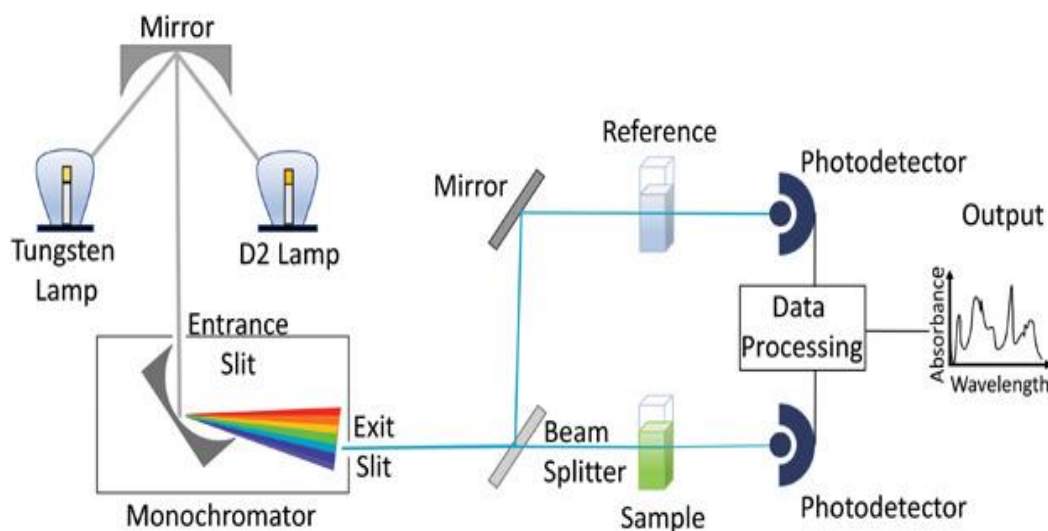


Fig 5.1 Schematic diagram of Uv-Vis Spectroscopy

The working of UV-Vis spectroscopy is based on the Beer-Lambert Law. In UV-Vis spectroscopy, a beam of light from the light source is passed through the sample in the cuvette. The monochromator selects a specific wavelength of light, and the intensity of the light passing through the sample is measured by the detector. The absorbance of the sample at the selected wavelength is then calculated using the Beer-Lambert Law.

The sample is typically prepared by dissolving it in a suitable solvent, and the concentration of the sample is usually known or can be determined by other methods. The absorbance is directly proportional to the concentration of the sample in the solution. A calibration curve can be constructed by measuring the absorbance of a series of solutions with known concentrations of the analyte. The concentration of an unknown sample can then be determined by comparing its absorbance to the calibration curve.

UV-Vis spectroscopy can be used for quantitative analysis, such as determining the concentration of a compound in solution, or qualitative analysis, such as identifying the presence of a specific functional group in a molecule. It is widely used in many fields, including chemistry, biochemistry, and materials science, due to its simplicity, sensitivity, and versatility.

5.1.3 APPLICATIONS OF UV SPECTROSCOPY

UV-Vis spectroscopy has a wide range of applications in various fields, including:

1. *Quantitative analysis:* UV-Vis spectroscopy is commonly used for quantitative analysis to determine the concentration of a compound in a solution. It is widely used in the pharmaceutical industry, food industry, and environmental testing.
2. *Qualitative analysis:* UV-Vis spectroscopy can be used for qualitative analysis to identify the presence of a specific functional group or chromophore in a molecule. This can be useful in the characterization of new compounds.

3. *Biochemistry*: UV-Vis spectroscopy is used to study the structure and function of biomolecules such as proteins, nucleic acids, and enzymes. It is used to monitor the folding and unfolding of proteins and the denaturation of enzymes.
4. *Chemical kinetics*: UV-Vis spectroscopy can be used to study chemical kinetics, such as the rate of a chemical reaction. The absorbance of a reaction mixture can be monitored over time to determine the rate of the reaction.
5. *Materials science*: UV-Vis spectroscopy is used to study the electronic properties of materials, such as semiconductors and nanoparticles. It can be used to determine the band gap and optical properties of materials.
6. *Environmental analysis*: UV-Vis spectroscopy is used to monitor water quality and the presence of pollutants in water. It is also used in air quality monitoring.
7. *Forensic science*: UV-Vis spectroscopy is used in forensic science to identify drugs, toxins, and other substances in biological samples.

Overall, UV-Vis spectroscopy is a powerful analytical tool with many applications in various fields. Its simplicity, sensitivity, and versatility make it a popular choice for researchers and analysts.

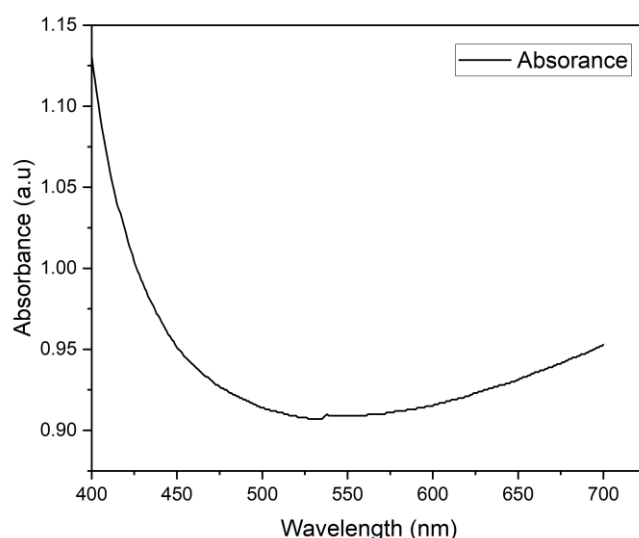


Fig 5.1.1 Undoped UV graph of SnO₂

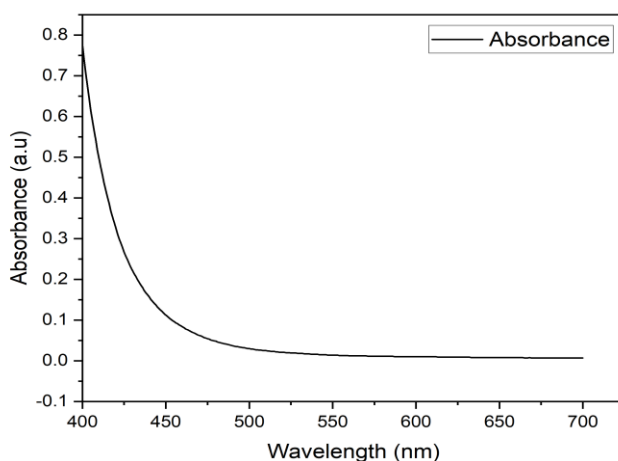


Fig 5.1.2 Bi-doped SnO₂ UV graph

The absorbance of the SnO₂ and Bi-doped SnO₂ thin film is obtained by using the UV-VIS spectroscopy technique. Fig 5.1.1 and Fig 5.1.2 shows the absorbance spectra for the pure SnO₂ and Bi-doped SnO₂ thin film. The maximum absorbance for pure SnO₂ thin film is at 0.90 to 0.95 a.u and the wavelength is 472nm. The maximum absorbance for Bi-doped SnO₂ thin film is at 0.1 to 0.2 a.u and the wavelength is 443nm. Therefore this SnO₂ and Bi-doped SnO₂ is suitable for solar cell application.

5.2 X-RAY DIFFRACTION

5.2.1 PRINCIPLE

X-ray diffraction (XRD) is a technique used to study the structure of crystalline solids. The principle behind XRD is the interaction of X-rays with the atoms in a crystal lattice, resulting in the diffraction of the X-rays in different directions.

The XRD technique is based on Bragg's law, which states that when a beam of X-rays is incident on a crystal lattice, the X-rays will be diffracted at a certain angle if the

distance between the crystal planes is equal to the wavelength of the X-rays. Mathematically, Bragg's law can be expressed as:

$$n\lambda = 2d \sin\theta$$

where n is an integer, λ is the wavelength of the X-rays, d is the distance between the planes of atoms in the crystal lattice, and θ is the angle of incidence of the X-rays.

When a beam of X-rays is directed at a crystal, the X-rays are scattered in different directions due to the diffraction of X-rays by the crystal lattice. The scattered X-rays form a diffraction pattern, which can be detected and analyzed to determine the crystal structure of the sample.

The diffraction pattern is typically recorded as a series of peaks at different angles, and the positions and intensities of these peaks are related to the crystal structure of the sample. The positions of the peaks correspond to the interplanar distances between the crystal planes, while the intensities of the peaks are related to the atomic arrangement and the number of atoms in the crystal.

XRD is a non-destructive technique and is widely used in materials science, chemistry, geology, and other fields to study the structure of materials. It is a powerful tool for the identification and characterization of crystalline materials and is used to determine the crystal structure, lattice parameters, and orientation of single crystals.

5.2.2 INSTRUMENTATION AND WORKING OF XRD

X-ray diffraction (XRD) instrumentation consists of the following main components:

1. *X-ray source*: Typically, a high-intensity X-ray source such as a rotating anode or synchrotron is used. The X-rays produced by the source are directed onto the sample.

2. *Sample holder*: The sample is mounted on a sample holder, which can be rotated and tilted to adjust the angle of incidence and the orientation of the crystal.
3. *Monochromator*: A monochromator is used to select a specific wavelength of X-rays. This is done by passing the X-rays through a crystal or a grating that diffracts the X-rays and selects a specific wavelength.
4. *Detector*: The scattered X-rays are detected by a detector, such as a scintillation counter or a CCD camera. The detector records the intensity and position of the diffracted X-rays to create a diffraction pattern.

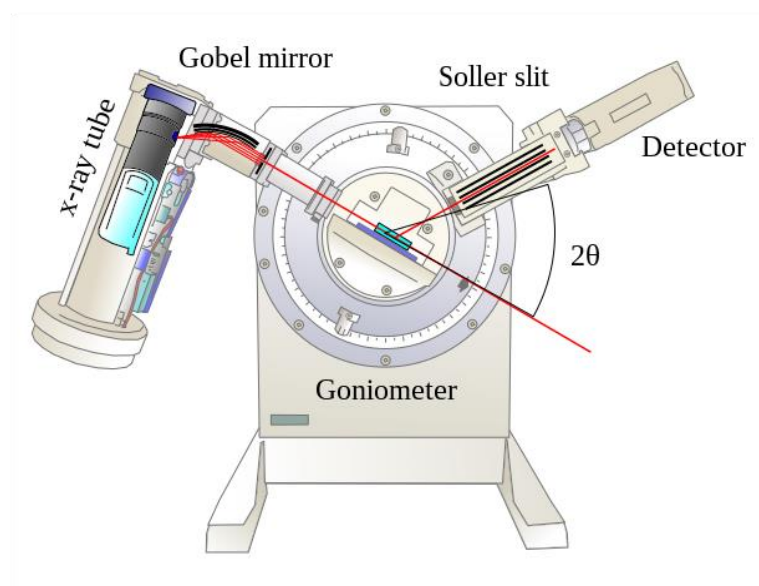


Fig 5.2 Schematic diagram of X-Ray diffractometer

The working principle of XRD can be described as follows:

1. The X-ray beam is directed onto the sample at a specific angle, known as the incident angle.

2. The X-rays interact with the atoms in the crystal lattice, causing them to diffract in different directions. The diffracted X-rays form a diffraction pattern, which is recorded by the detector.
3. The diffraction pattern is analyzed to determine the crystal structure of the sample. The positions and intensities of the peaks in the diffraction pattern are related to the crystal structure, lattice parameters, and orientation of the crystal.
4. The crystal structure can be determined by comparing the diffraction pattern with reference patterns of known structures in a database.

XRD can be used to identify and characterize crystalline materials, including minerals, metals, ceramics, and polymers. It is a powerful tool for studying the crystal structure of materials, and it can be used to determine the degree of crystallinity, lattice defects, and the size and shape of crystallites. XRD is widely used in materials science, chemistry, geology, and other fields to study the structure of materials.

5.2.3 XRD APPLICATION

X-ray diffractometers have numerous applications in a variety of fields. Some of the major applications are:

1. Material identification: XRD is widely used to identify unknown materials, including minerals, metals, ceramics, and polymers. By comparing the diffraction pattern of an unknown sample to a database of known patterns, the identity of the material can be determined.
2. Crystal structure determination: XRD can be used to determine the crystal structure of a material, including the unit cell parameters, space group, and atomic positions. This information is important in understanding the physical and chemical properties of materials.
3. Quality control: XRD is used in quality control to ensure that materials have the desired crystal structure and composition. This is particularly important in the manufacture of pharmaceuticals, where the crystal structure of the active ingredient can affect its efficacy.

4. Forensics: XRD is used in forensics to identify unknown substances, such as drugs or explosives.
5. Geological analysis: XRD is used in geology to identify minerals and rocks, and to study their properties and formation.
6. Environmental analysis: XRD can be used to analyze environmental samples, such as soil or water, to identify minerals and other compounds present.
7. Pharmaceutical development: XRD is used in the development of new pharmaceuticals to study the crystal structure and polymorphism of active ingredients, and to ensure that the final product has the desired properties.
8. Nanomaterials: XRD is used to study the structure of nanomaterials, which have unique properties due to their small size.

Overall, XRD is a powerful analytical technique with a wide range of applications in materials science, chemistry, geology, environmental science, and many other fields.

Special techniques to characterize the thin film samples

Several special techniques can be used to characterize thin films using X-ray diffraction (XRD):

1. *Grazing incidence X-ray diffraction (GIXRD)*: GIXRD is a technique that is used to study thin films deposited on a substrate. In this technique, the X-ray beam is incident on the sample at a very low angle (typically less than 1 degree). This causes the X-rays to penetrate only a few atomic layers into the sample, allowing the structure of the thin film to be studied independently of the substrate.
2. *Pole figure analysis*: Pole figure analysis is a technique that is used to study the preferred orientation (texture) of thin films. In this technique, the thin film is rotated about an axis perpendicular to the substrate, and the diffraction pattern is recorded at each orientation. By analyzing the intensity and position of the diffraction peaks, the orientation of the crystal lattice can be determined.
3. *Residual stress analysis*: Thin films deposited on a substrate can be subjected to residual stress due to differences in the thermal expansion coefficients of the film

and substrate. XRD can be used to measure the residual stress in the thin film by analyzing the position and intensity of the diffraction peaks.

4. *High-resolution X-ray diffraction (HRXRD)*: HRXRD is a technique that is used to study the crystal structure of thin films with high resolution. In this technique, a monochromatic X-ray beam is used to select a specific wavelength, and the diffraction pattern is recorded with high precision. HRXRD can be used to determine the thickness, composition, and strain in thin films.
5. *X-ray reflectivity (XRR)*: XRR is a technique that is used to measure the thickness and density of thin films. In this technique, the X-ray beam is incident on the thin film at a high angle (typically greater than 0.1 degrees), causing the X-rays to reflect off the surface. The intensity of the reflected X-rays is measured as a function of the incident angle, and the thickness and density of the thin film can be determined from the analysis of the reflectivity curve.

Overall, these special techniques can provide valuable information on the crystal structure, texture, thickness, composition, and residual stress of thin films using XRD.

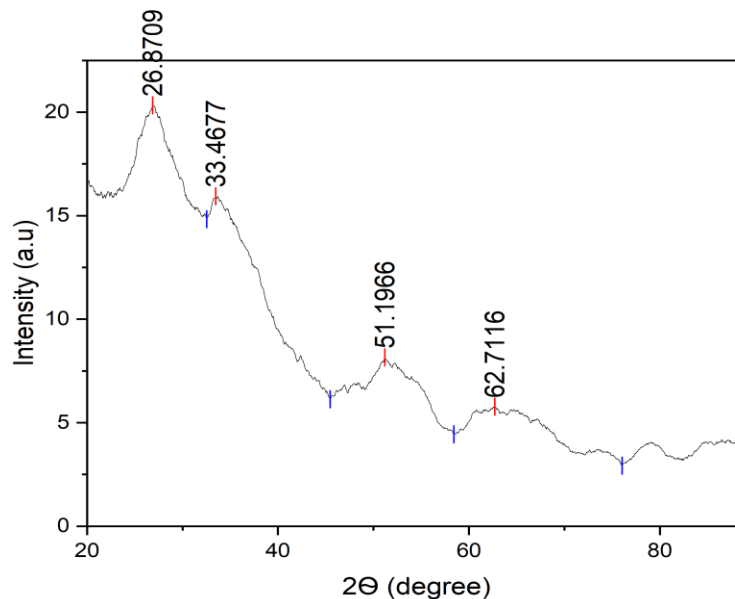


Fig 5.3 XRD graph for undoped SnO₂

Fig 5.3 shows the XRD graph for undoped SnO_2 and its peaks as plotted on the graph itself. The intensity of the undoped SnO_2 will be varied concerning the 2θ of the XRD.

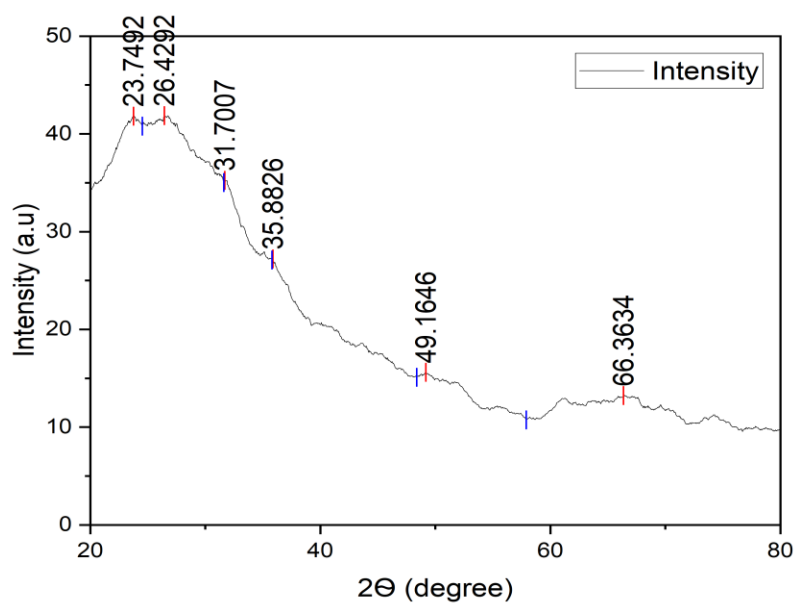


Fig 5.4 XRD Graph for Bi-doped SnO_2

Thus fig 5.4 shows the graph of XRD for Bi-doped SnO_2 with the peak that will be plotted on the graph itself. The intensity will vary for Bi-doped SnO_2 concerning the 2θ of the XRD.

5.3 HALL EFFECT MEASUREMENTS

Hall effect measurements are used to determine the electrical properties of a material, such as its carrier concentration, mobility, and type (i.e., whether it is an electron or a hole conductor). The Hall effect refers to the phenomenon where a magnetic field perpendicular to a current-carrying conductor generates a voltage across the conductor, perpendicular to both the current and the magnetic field.

The basic principle of Hall effect measurements involves passing a current through a thin rectangular sample of the material in the presence of a magnetic field perpendicular to the current. The magnetic field causes the charge carriers (i.e., electrons or holes) in the material to deflect from their original path, resulting in an accumulation of charge on one side of the sample and a depletion of charge on the other side. This creates a transverse voltage, known as the Hall voltage, which can be measured using a voltmeter.

The Hall voltage is proportional to the strength of the magnetic field and the carrier density and is inversely proportional to the carrier mobility. By measuring the Hall voltage at different magnetic field strengths and plotting it against the magnetic field, the carrier concentration and mobility can be determined.

Hall effect measurements can also be used to determine the type of conductivity (i.e., whether the material is an electron or a hole conductor) by analyzing the sign of the Hall voltage. If the Hall voltage is negative, then the material is an electron conductor, while a positive Hall voltage indicates a hole conductor.

Hall effect measurements are commonly used in the characterization of semiconductors, metals, and other materials with electrical conductivity. They are particularly useful in the development of electronic devices, such as transistors and solar cells, where a precise understanding of the electrical properties of the materials is crucial.

Hall effect measurement on thin films

Hall effect measurements can also be performed on thin films to determine their electrical properties, such as carrier concentration and mobility. The basic principle of Hall effect measurements on thin films is similar to that on bulk materials but with some additional considerations.

One of the main challenges in performing Hall effect measurements on thin films is the need to ensure that the magnetic field is perpendicular to the film plane. This can be achieved by either placing the thin film in a perpendicular magnetic field or by using a geometry where the magnetic field is parallel to the film plane but the current is passed through the film in a direction perpendicular to the magnetic field.

Another consideration when performing Hall effect measurements on thin films is the influence of the substrate. Since the substrate can affect the electrical properties of the thin film, it is important to choose a substrate material that has minimal impact on the Hall effect measurements. Additionally, the thickness and composition of the thin film can also influence the Hall effect measurements, so it is important to carefully control the deposition process and characterize the thin film before performing the measurements.

In some cases, the thickness of the thin film may be too small for standard Hall effect measurements, and alternative methods may be used, such as micro-Hall effect measurements or transverse resistance measurements. Micro-Hall effect measurements use a smaller probe size to perform Hall effect measurements on a smaller area of the thin film. Transverse resistance measurements involve measuring the resistance of the thin film in the transverse direction to the current flow and magnetic field, which can be used to determine the Hall voltage and thus the electrical properties of the thin film.

Thin film Hall effect measurements can provide information on the carrier concentration and mobility of the film, as well as its type of conductivity. However, the thin film geometry can present some challenges in the measurement process. For

example, the thickness of the film can affect the measured Hall voltage, and the presence of the substrate can cause additional contributions to the measured signal.

To overcome these challenges, it is important to carefully design the measurement setup and analyze the data using appropriate models. For example, modeling techniques such as the two-layer model or the van der Pauw method can be used to account for the contribution of the substrate to the Hall voltage signal.

Overall, Hall effect measurements on thin films can provide valuable information on the electrical properties of the films, which is important for their use in electronic devices such as transistors, sensors, and solar cells.

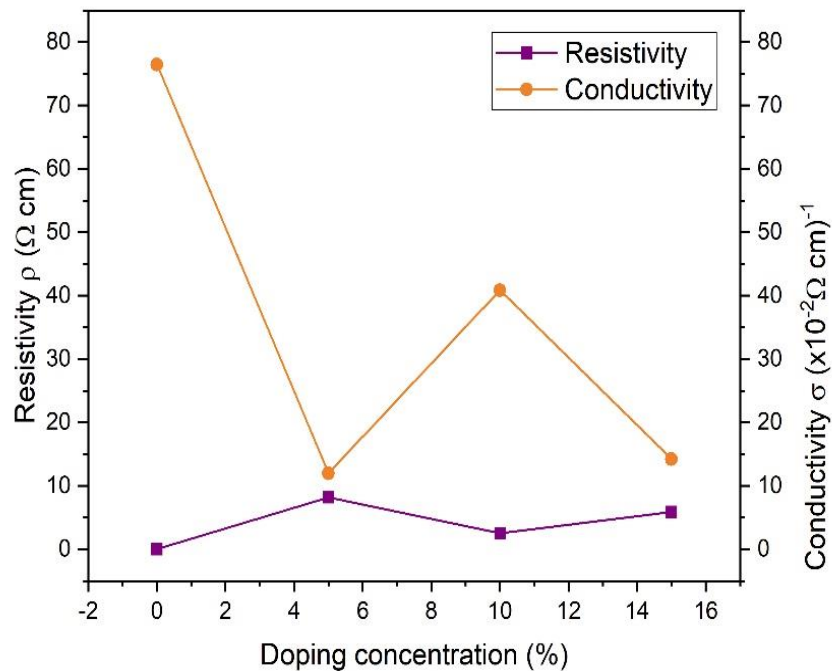


Fig 5.5 Graph for conductivity vs resistivity

From this (fig 5.5) graph shows the plots for conductivity versus resistivity is measured in hall effect. The conductivity is high for the doping concentration of 10% Bi-doped SnO_2 i.e., $40.854 \times 10^{-2} \Omega \text{ cm}^{-1}$, and its resistivity will be $2.514 \Omega \text{ cm}$.

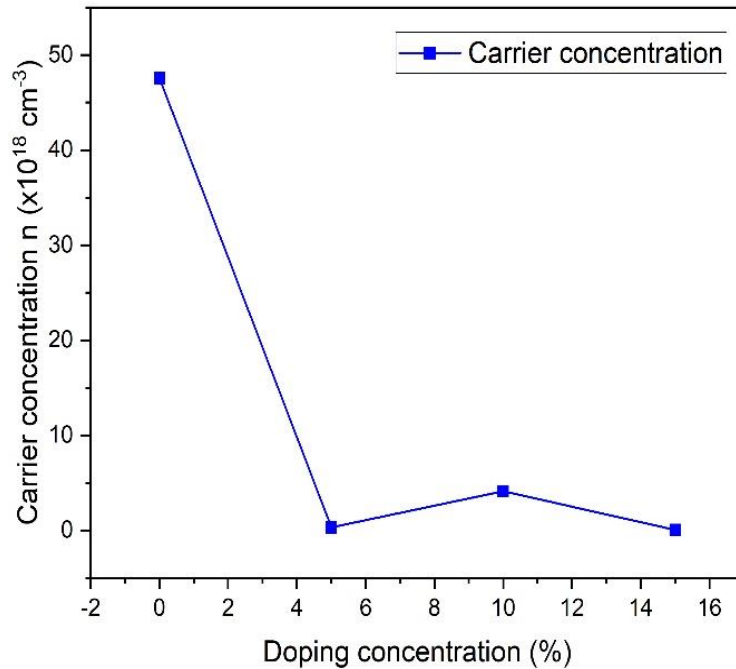


Fig 5.6 Graph for carrier concentration

From this (fig 5.6) the graph for carrier concentration for the Bi-doped SnO_2 will be drawn by the hall effect. The carrier concentration will be increased to $4.114 \times 10^{18} \text{ cm}^{-3}$ for 10% of the doping concentration. Thus the doped SnO_2 is better than undoped SnO_2 for solar cell applications.

CHAPTER 6

CONCLUSION AND REFERENCE

CONCLUSION

The synthesis and characterization of the undoped and Bi-doped SnO₂ thin film for solar cell application by a dip coating method are successfully done. The optical and electrical properties are studied for both undoped and Bi-doped SnO₂ thin films. The UV shows 0.90 to 0.95 a.u of absorbance and wavelengths of 472 and 443 nm. The XRD for the undoped and Bi-doped SnO₂ thin film is also been obtained and its point is plotted on the graph itself. The hall effect for the undoped and Bi-doped SnO₂ thin film has also been studied. The conductivity is been obtained for the thin film is about $40.854 \times 10^{-2} \Omega \text{ cm}^{-1}$ and the resistivity of the thin film is about $2.514 \Omega \text{ cm}$. The carrier concentration for Bi-doped SnO₂ thin film is $4.114 \times 10^{18} \text{ cm}^{-3}$. Thus the carrier concentration and resistivity show the good conductivity of the Bi-doped SnO₂ thin film.

From the above results, it is found to be Bi-doped SnO₂ solar cells are more efficient than the SnO₂ solar cell in solar cell applications. It almost increases by 75% of its efficiency than pure SnO₂ solar cells.

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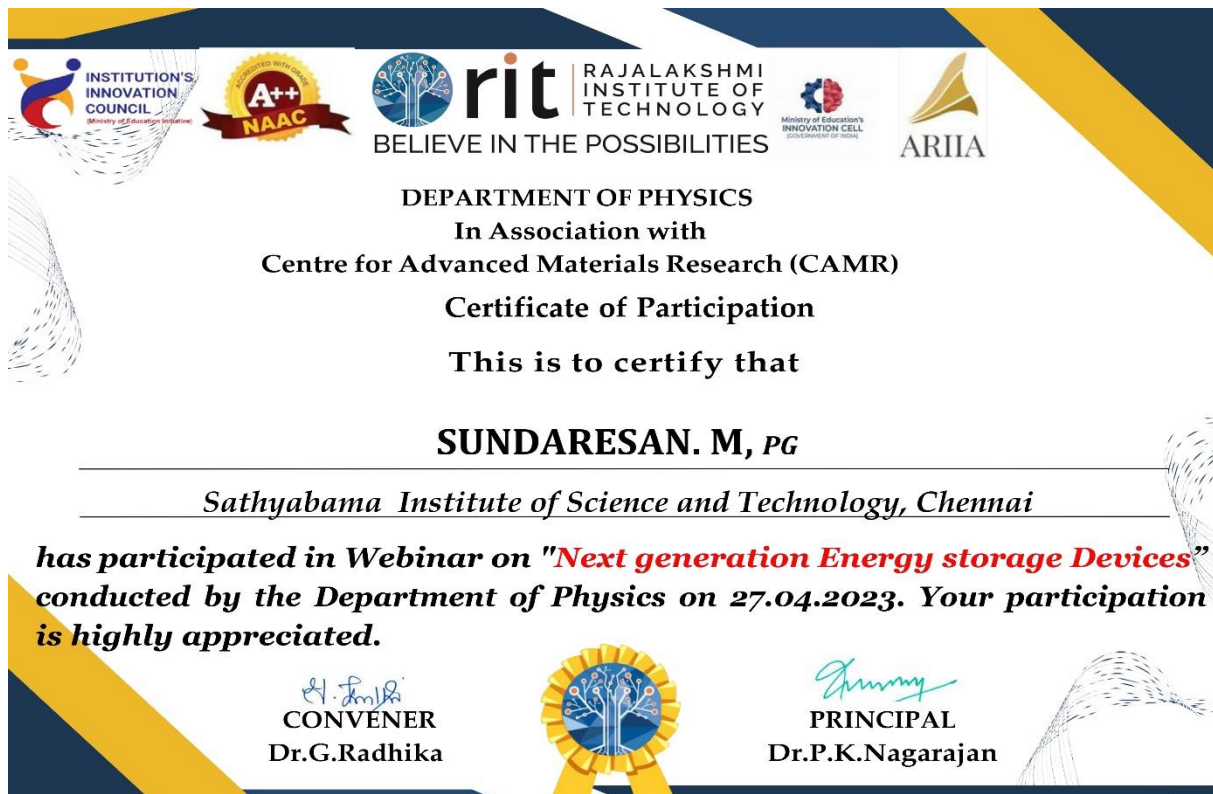
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LIST OF CONFERENCE

Author	Conference	Date	Title	Presentation
M. Sundaresan	Centre for Advanced Material Research (CAMR)	27/04/2023	Next Generation Energy Storage Devices	Oral Presentation on 27/04/2023
M. Sundaresan	GCAM	29/04/2023	Green Clean and Affordable Magnets	Oral Presentation on 29/04/2023





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