

STUDIES ON THE CHARACTERISTICS OF SnO₂ THIN FILMS
DOPED WITH FLUORINE FOR SOLAR CELL APPLICATION
SYNTHESIZED BY
SOL-GEL SPIN COATING METHOD

Submitted by

THANIMA N M

[Reg.no. 40590001]

in partial fulfillment of the requirements for the award of

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SCHOOL OF SCIENCE AND HUMANITIES

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INSTITUTE OF SCIENCE AND TECHNOLOGY
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Accredited with Grade "A" by NAAC
JEPPIAAR NAGAR, RAJIV GANDHI SALAI, CHENNAI - 600 119

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BONAFIDE CERTIFICATE

This is to certify that this project report is the bonafide work of **THANIMA.N.M** (REG.NO. 40590001) who carried out the project entitled "**Studies on the characteristics of SnO₂ thin films doped with fluorine synthesized by sol-gel spin coating method**" under my supervision from **NOVEMBER 2021 TO MAY 2022**

Internal Guide

DR. C. RAMESHKUMAR

Head of the Department

DR. S. RAVICHANDRAN

Submitted for Viva voice Examination held on _____

Internal Examiner

External Examiner

DECLARATION

I **THANIMA.N.M (Reg. No. 40590008)** hereby declare that the Project Report entitled “**Studies on the characteristics of SnO₂ thin films doped with fluorine synthesized by sol-gel spin coating method**” done by me under the guidance of **Dr.C.RAMESHKUMAR** is submitted in partial fulfillment of the requirements for the award of Master of science degree in Physics.

DATE:

PLACE:

(THANIMA N M)

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ABSTRACT

In this study, Fluorine-doped tin oxide (SnO_2 : F or FTO) thin films were deposited on glass substrates by sol-gel spin coating. The method was found to be very economic and functional. The basic material used is $\text{SnCl}_2 \cdot 2\text{H}_2\text{O}$, while the doping material used is NH_4F with variations in concentrations of dopants 0% and 10%. The substrate used is glass slides. The synthesis of the thin layer includes substrate preparation, sol-gel making, thin film making, and heating process. At this stage SnO_2 :F is deposited on a glass substrate with sol-gel spin coating technique at the concentration of 1 molar with doping levels of Fluorine 0 and 10%, and treated with maturation for 24 hours. Making a thin layer using a spin coater at a speed of 2000 rpm for 3 minutes. The layer made consists of three layers.

The structural investigation of as-prepared films was performed using Raman spectroscopy. Optical characteristics were investigated using an UV visible spectrometer. Electrical characteristics were done using Hall effect measurement. Optical characteristics were investigated using a UV visible spectrometer. The optical band gap of tin oxide is calculated using Tauc's plot. The direct band gap value was found to be 3.33 eV for 10% FTO film. The effect of fluorine doping concentration on its band gap was also studied in this report by comparing the result of this study with the results of pure SnO_2 film. The value is found to be about 3.39-3.49 eV for solution and thin film samples of SnO_2 . The transmittance of pure SnO_2 sample is about above 90. Therefore, it is found suitable for photo voltaic devices. Electrical studies of FTO film also been carried out. The obtained results indicated that the structures, optical and electrical properties of the films were greatly affected by the fluorine concentration ratio.

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LIST OF ABBREVIATIONS

TF	Thin film
FTO	Fluorine doped tin oxide
LCD	Liquid Crystal Diode
PLD	Pulsed laser deposition
SnO₂	Stannous chloride
NH₄F	Ammonium fluoride
CVD	Chemical Vapor Deposition
PVD	Physical Vapor Deposition
MBE	Molecular Beam Epitaxy
HCl	Hydrochloric acid
RPM	Rotation Per Minute
UV-VIS SPECTROSCOPY	Ultra Violet-Visible Spectroscopy
XRD	X-Ray Diffraction

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

This chapter covers the fundamentals of thin film technology such as its morphology, properties, deposition and applications. Thin film physics has made noticeable growth during recent years and the rate of its progress is accelerating with the development of science in our society. The most regularly seen thin films in our everyday life are soap films, oil floating in water, paints, nail polish. A thin film is a layer of substance ranging from nano meter to micro meter thickness. It is a layer of material with thickness less than one micro meter range; it was firstly used for the reason of designing integrated circuits. Based on the thickness of the films are categorised as ultrathin films, very thin films and thick films. If the films exist by itself they are generally known as foil and often the films are adhered to a substrate. Thin films are often treated as two dimensional specimens as the third dimension thickness is insignificant. A common use of thin films is in household mirrors where the thin film silver reflective interface is made in the back of the sheet of glass. There are numerous ways in which thin films of a material can be coated on to a substrate. Presently, the process not only involve physical or chemical but also natural methods, green synthesis. Physical methods include use of expensive appliances needs high pressure and high temperature. Physical methods also require wide area for setting up machines for production. Chemical methods include use of toxic chemicals which are dangerous to environment and personnel. Green routes of synthesis generate less pollutant and are energy efficient and low cost. The main merits of thin films are low material consumption, easy processing and possible utilization. This chapter contributes a lengthy introduction to the basic concepts of thin-film technology, containing the deposition processes, structure, and some optical, mechanical, magnetic and electrical properties. Deposition of thin films by the main physical deposition methods of vacuum evaporation, electron beam evaporation, laser beam evaporation and sputtering are described in some detail, and by the chemical deposition methods of chemical bath deposition, dip coating and spin coating.

1.2 DEFINITION

Thin film can be described as a thin layer of substance, where the thickness ranges from several nano meters to few micro meters. A stack of thin films is called a multilayer. The structure of thin films is differentiated into amorphous and polycrystalline structure based on the synthesis conditions as well as the nature of the material. Thin films are made up of two parts: the layer and the substrate where the films are deposited on it. They are layers of substance deposited on a bulk substrate in order to reveal characteristics that cannot be straightforwardly attained by the base material. Thin film deposition refers to the act of applying a thin film of any substance on a surface, whether a substrate or already deposited layers. Generally, however, a thin film would probably be thinner than one-micron, or at most a few microns. This may possibly be well imagined in terms of a single strand of spider silk, hundreds of which are carried in a single thread of a spider web. A familiar model is the household mirror, which has a thin metal coating on the back of a sheet of glass to form a reflective interface. The process of silvering was once commonly used to produce mirrors, while nowadays the metal layer is deposited using methodology such as sputtering.

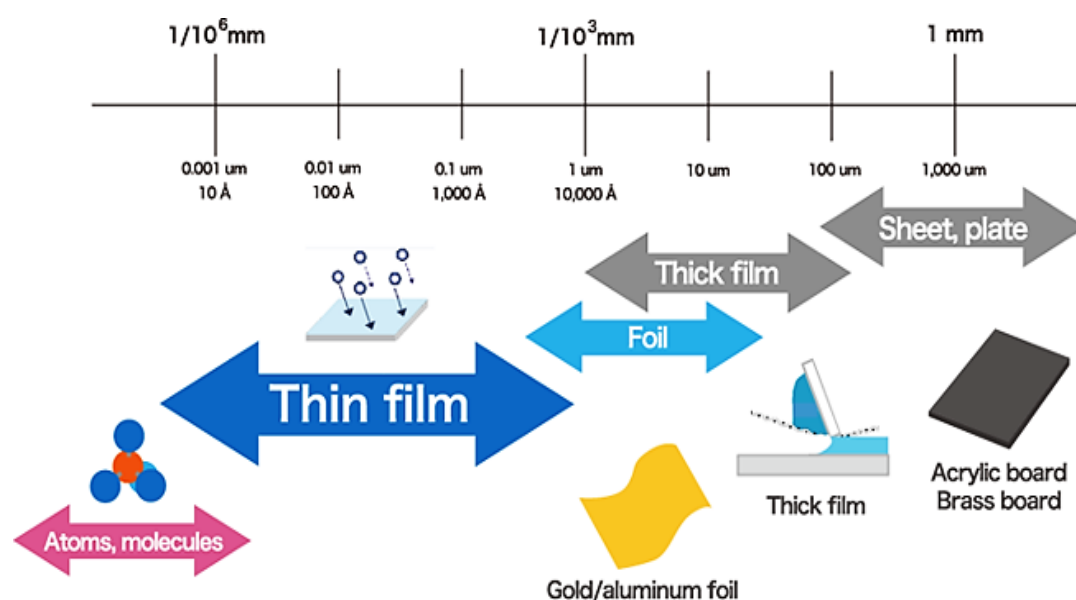


Fig. 1.1 Thin film technology

1.3 PROPERTIES OF THIN FILMS

1.3.1 MECHANICAL PROPERTIES

Mechanical properties of thin films often differ from the bulk materials. Due to high yield Strengths, thin films can support very high residual stresses. This residual stress can be relieved later during processing or in the actual device operation through plastic deformation, thin film fracture. The elastic moduli is not that different they are coming from the atom-atom bonds are the same in bulk and in thin films. Parameters of plastic deformation like the Critical yield strength, hardness can be far larger than bulk values. If you deposit a perfectly Brittle material like Si on a flexible substrate, you can roll up your substrate and find that the thin film will not break. It's simply a matter of the radius of curvature being far larger than the film thickness.

1.3.2 OPTICAL PROPERTIES

Bulk materials that appear opaque because of the absorption length of light may be fully transparent as a thin layer. Even some very thin metal layers become transparent to visible light. Optical properties of a solid come from its interactions with electromagnetic waves and manifested in optical frequencies. Optical properties of films have been studied extensively because of their applications in various optical and electro- optical devices and it has been found that there is often a considerable deviation of optical parameters from that of a bulk material. From reflection, transmission and absorption processes, it is possible to evaluate the optical constants such as refractive index (n), absorption index or extinction coefficient (k) and absorption coefficient (α) and in turn also the complex dielectric constants (ϵ^*) of a solid

1.3.3 ELECTRICAL PROPERTIES

The film thickness, the lattice dimensions, the purity, the surface roughness and the imperfect level of the layer are must significant parameters define the type, mechanism and stability of the electrical transport. We have $\sigma = \sum_i (q_i \cdot n_i \cdot \mu_i)$ with q , n , μ = charge, carrier concentration, and mobility, respectively, of the carriers involved. Going from bulk to a thin film, the carrier concentration changes and that the system becomes a two-dimensional electron gas. In the case of metallic films

its resistivity has been found to be much higher than that of the corresponding bulk metal and it decreases with the increase of film thickness eventually attains a Value often approaching that of the bulk.

1.3.4 MAGNETIC PROPERTIES

The maximum value of the intensity of magnetization is of the same order of magnitude as for a bulk metal. The magnetization is independent of the crystal size and the thickness of the film. The remnance depends on the crystal size but not on the thickness. The high values of the Coercive force may be due to the minute size of the crystals.

1.4 IMPORTANCE

In today's world, thin films are commonly thought of in connection with semiconductors. However, thin films are important in a multiplicity of other areas where coatings only a few microns thick are needed. The thin film is important because it changes the surface interactions of the newly formed platform from the bulk substrate properties. Thin films are not defined by their thickness alone, however, as they are of various thicknesses depending on their properties. For instance, a thin film at an atomic level is created by the deposition of atoms or molecules, as by evaporation. On the other hand, particle deposition would create a thick film, as when paint particles are deposited.

Although the study of thin film phenomena dates back well over a century, it is really only over last four decades that they have been used to a significant extent in practical situations. Advances in thin film deposition techniques during the 20th century have enabled a wide range of technological breakthroughs in areas such as magnetic recording media, electronic semiconductor devices, Integrated passive devices, LEDs, optical coatings (such as antireflective coatings), hard coatings on cutting tools, and for both energy generation (e.g. thin-film solar cells) and storage (thin-film batteries). It is also being applied to pharmaceuticals, via thin-film drug delivery. Thin Film materials have already been used in semiconductor devices, wireless communications, Telecommunications, integrated circuits, rectifiers, transistors, solar cells, light-emitting diodes, Photoconductors, light crystal displays, magneto-optic memories, audio and video systems, Compact

discs, electro-optic coatings, memories, multilayer capacitors, flat-panel displays, smart Windows, computer chips, magneto optic discs, lithography, micro-electromechanical systems and multifunctional emerging coatings, as well as other emerging cutting technologies. Thin films are routinely used as electronic, optical, protective, even decorative coatings.

In fact, engineers trace the origins of thin-film deposition back to decorative gold leaf coatings on ornaments dated as early as 2600 BCE. The method of depositing extremely thin gold coatings is known as gilding; a term that encompasses even the most rudimentary technique where gold foil was simply hammered onto a surface with an intermediary adhesive layer. Although this may sound crude by today's standards – where thin films can be chemically synthesized in ultra-high vacuum (UHV) conditions – some of the most common methods of thin film deposition still rely on the application of force to coat a substrate: Spin coating, for instance.

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

1.5 APPLICATIONS

The dawn of 21st century has seen the beginning of the applications of thin film technology in commercial products. Over time, the applications of thin films have grown exponentially and have become an integral part of both industrial and research processes. Deposition of the thin film can make a material to be versatile and be used for different applications, by improving the surface properties like wear, fatigue, corrosion, hardness, and other surface related phenomena. Thin films have a great impact on the modern era of technology. Thin films are considered as backbone for advanced applications in the various fields such as optical devices, environmental applications, telecommunications devices, energy storage devices, and so on.

Applications of thin films may be grouped under the following generic areas:

1.5.1 DATA STORAGE

Magnetic thin films are used for Data storage. As the data storage density in cutting edge Microelectronic devices continues to increase, the super paramagnetic effect poses a problem for magnetic data storage medium. One of the methods to overcome this is the use of thermo-mechanical data storage technology. In this method, data is written by nanoscales mechanical Probe as an indentation on a surface, read by a transducer built into the probe and then erased by the application of heat.

1.5.2 OPTOELECTRONIC DEVICES AND OPTICAL COATING

Thin film coating is essential for optical coating. An optoelectronic thin-film chip comprises at least one radiation-emitting region in an active Zone of a thin-film layer and a lens placed downstream of the radiation emitting region, lens being greater than the lateral extent of the radiation emitting region. Thin films are now a day extensively used for the fabrication of various optical systems particularly as anti- reflection coatings, high reflecting multi- layer films, narrow and wide band reflection and transmission filters, polarizer, beam splitters etc. An optical coating is one or more thin layers of material deposited on an optical component such as a lens or mirror, which alters the way in which they reflect and transmits light. Infrared reflecting coatings are applied to filament lamps to increase the luminous flux intensity. Commercial demand for thin film coating is also on the rise in the optical data storage devices like computer memory and storage disk. They serve as a protective coating on the surface to and act as a shield against temperature rise. Thin film has also been used extensively in coating window glass and mirror to prevent heat from passing through.

1.5.3 THIN FILM SOLAR CELLS

Thin film solar-cell, type of device that is designed to convert light energy into electrical energy (Through the photovoltaic effect) and is composed of micron-thick photon-absorbing material Layers deposited over a flexible substrate. Thin-film solar cells were originally introduced in the 1970s by researchers at the Institute of Energy Conversion at the University of Delaware in the United States. Thin film

solar cells are favourable because of their minimum material usage and rising efficiencies. Thin film solar cells are of low cost and are energy efficient.

Throughout the Early 21st century the potential for thin-film applications increased greatly, because of their flexibility, which facilitates their installation on curved surfaces as well as their use in building integrated photovoltaic cells.

Electronic component and display. The production of electronic components such as semiconductors, single and multilayer metal conductor film and microelectronic integrated circuits have undoubtedly found enormous and vast applications for thin films deposition. Compound conductor films for semiconductor, dielectric and insulating material, and metal refractory silicide conductors have also benefited immensely from thin film deposition. The fabrication of electronic displays requires conductive and transparent films, luminescent or fluorescent film as well as dielectric and insulating layers

1.5.4 THIN FILM LITHIUM-ION BATTERIES

They are similar to lithium-ion batteries, but they are composed of thin materials, some only nano meters or micro meters thick, which allow for the finished battery to have thickness in the milli meter range. These batteries exhibit the same voltage and current as their bulky counterparts, but their thinner dimensions allow for greater applications such as making thinner electronic devices, like Cell phones and laptops and even implantable medical devices and reducing the weight of common devices that run on battery power because of the high energy density of batteries. These batteries can be formed into any shape and they can be stacked, to be used in parallel, thus even further reducing the space needed for a battery of flexible substrates

1.6 THIN FILM DEPOSITION TECHNIQUES

The crucial issue for all applications of thin films depends on their morphology and the stability. The morphology of the thin films strongly hinges on deposition techniques. The controlled synthesis of materials as thin films is a fundamental step in many applications. Thin films can be deposited by the physical and chemical routes

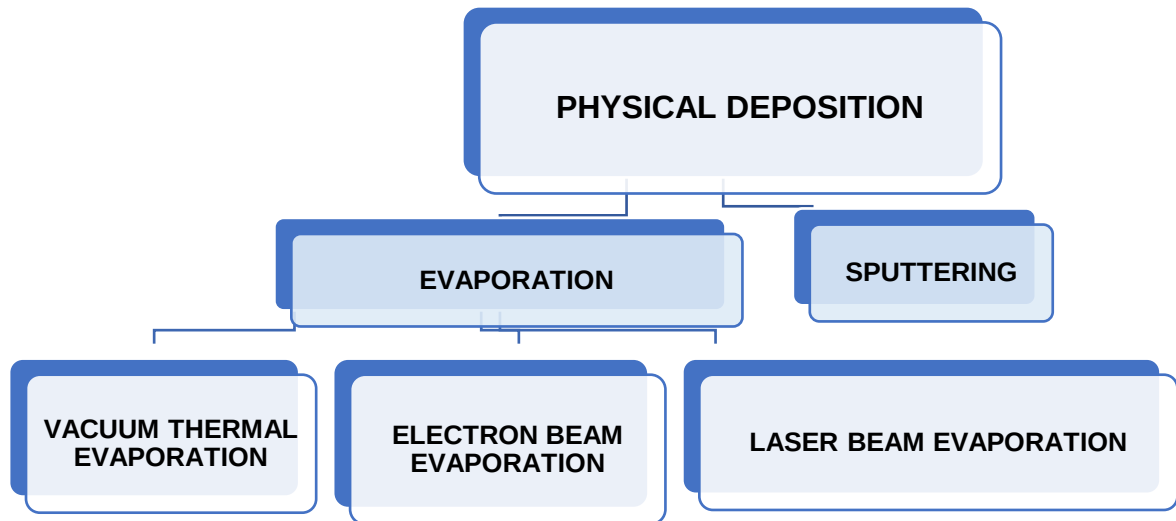


Fig. 1.2 Physical deposition techniques

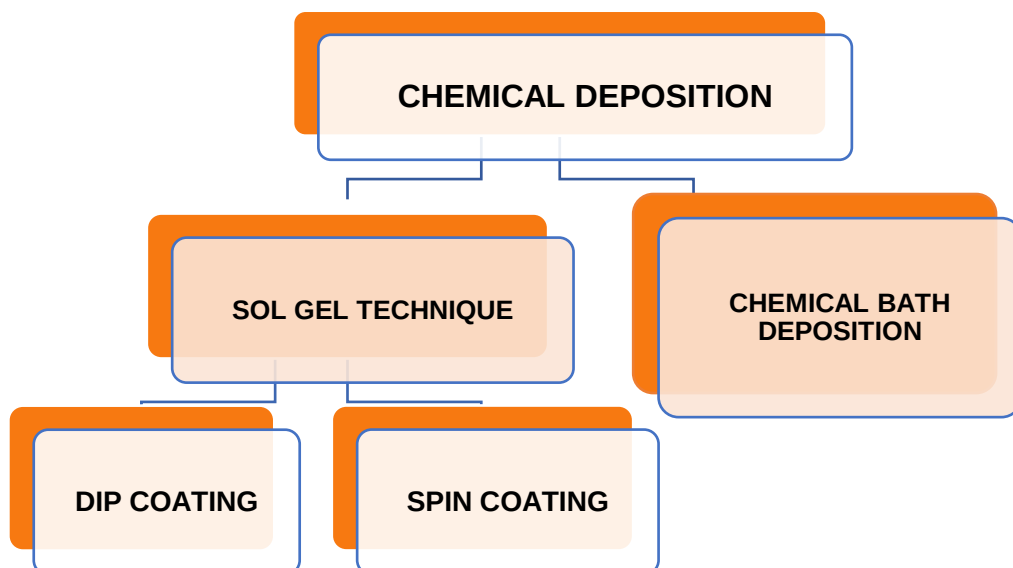


Fig. 1.3 chemical deposition techniques

1.6.1 PHYSICAL DEPOSITION TECHNIQUES

1.6.1.1 EVAPORATION TECHNIQUES

Evaporation methods are considered as the common deposition of materials in the form of thin-layer films. The general mechanism of these methods is obtained by changing the phase of the material from solid phase to vapor phase and converting again to solid phase on the specific substrate. It takes place under vacuum or controlled atmospheric condition.

1.6.1.1.1 VACUUM THERMAL EVAPORATION TECHNIQUE

Vacuum evaporation technique is the simplest technique used to prepare amorphous thin films especially chalcogenide films such as CdSSe, MnS, Ge-Te-Ga, and so on. In general, chalcogenide materials can be used for memory-switching applications, phase-change materials, and solar applications. The technique of thermal evaporation is strongly dependent on two parameters: thermally vaporized material and applying a potential difference to the substrate under medium- or higher-vacuum level ranging from 10^{-5} to 10^{-9} mbar. The schematic diagram for thermal evaporation is shown in Figure.1.4

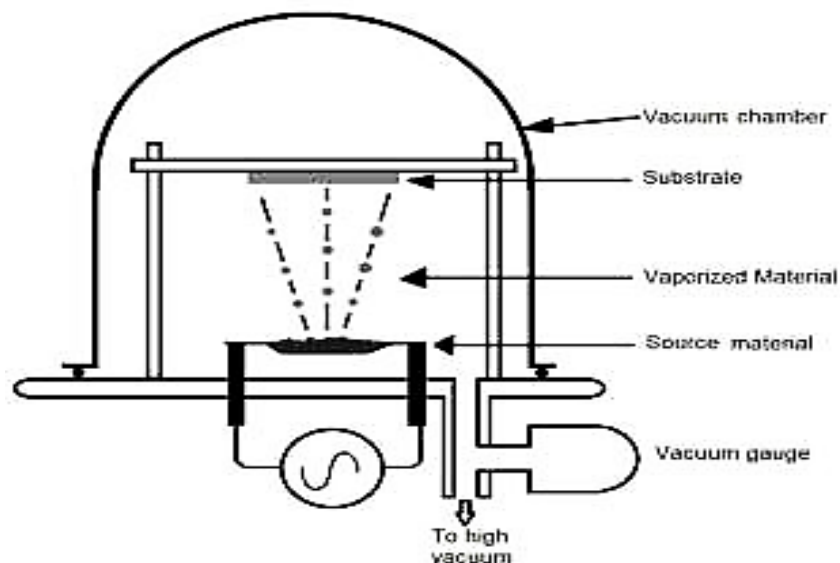


Fig. 1.4 Vacuum thermal evaporation

1.6.1.1.2 ELECTRON BEAM EVAPORATION

This type of evaporation is another method of physical deposition where the intensive beam of electrons is generated from a filament and steered through both electric and magnetic fields to hit the target and vaporize it under vacuum environment as shown in figure. Thin films prepared by electron beam evaporation are of good quality and purity. Large categories of materials can be prepared by electron beam evaporation technique such as amorphous and crystalline semiconductors, metals, oxides and molecular materials.

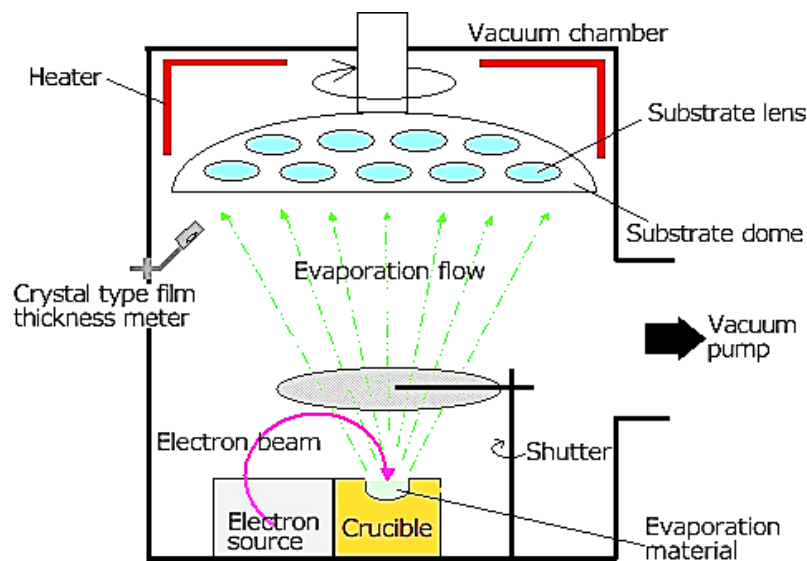


Fig. 1.5 Electron beam evaporation

1.6.1.1.3 LASER BEAM EVAPORATION (PULSED-LASER DEPOSITION)

Pulsed-laser deposition (PLD) is another physical deposition technique to deposit the thin-film-coating system. During the thin-film deposition process, the laser beam is used to ablate the material for depositing the thin films inside a vacuum chamber as shown in figure. Different kinds of laser sources are being used to ablate the target. The most common sources are Nd-YAG laser, KrF (248 nm), and XeCl (308 nm). When the laser beam strikes the target material, it produces the plume which could deposit on the various substrates. The created plume may contain neutral- and ground-state atoms and ionized species. In the case of metal oxide thin films, oxygen is used to deposit the oxides of metals. The thin-film

quality from the PLD depends on the various parameters such as wavelength of the laser, energy, ambient gas pressure, pulsed duration, and the distance of the target to the substrate. The ablation process during the deposition may control and monitor by using laser-induced fluorescence, laser ablation molecular isotopic spectroscopy, and optical emission spectroscopy. The morphology of the deposited thin films is also affected by the substrate temperature. The coating of thin films through PLD follows three modes: Frank—van der Merwe, Stranski-Krastanov, and Volmer—Weber. PLD has some advantages over other physical deposition systems because of its fast deposition time and its compatibility to oxygen and other inert gases.

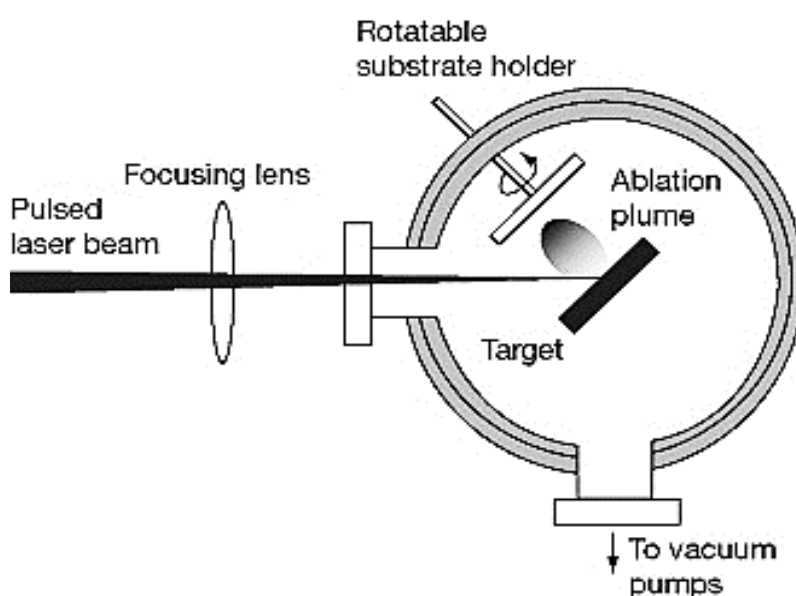


Fig. 1.6 Laser beam evaporation

1.6.1.2 SPUTTERING TECHNIQUE

Sputtering technique is mostly used for depositing metal and oxide films by controlling the crystalline structure and surface roughness. The simple form of the sputtering system consists of an evacuated chamber containing metallic anode and cathode in order to obtain a glow discharge in the residual gas in the chamber. Also, an applied voltage in the order of several KeV with pressure more than 0.01 mbar is sufficient for film deposition. The sputtering process depends on the bombardment of the ions released from the discharge to the molecules in the cathode leading to the liberation of the molecules from the cathode with higher

kinetic energy. The atomic weight of the bombarding ions should be nearly to that of the target material in order to maximize the momentum transfer. These molecules move in straight lines and strike on the anode or on the substrate to form a dense thin film. The process of sputtering has several advantages. High-melting point materials can be easily formed by sputtering. The deposited films have composition similar to the composition of the starting materials. Sputtering technique is available to use for ultrahigh vacuum applications. The sputtering sources are compatible with reactive gases such as oxygen. Contrarily, thick coatings cannot be obtained and there is a difficulty to deposit uniformly on complex shapes. There are two common types of sputtering process: direct current (DC) and radio frequency (RF) sputtering. The first one depends on DC power, which is generally used with electrically conductive target materials. It is easy to control with low-cost option. The RF sputtering uses RF power for most dielectric materials. A common example for sputtered films is aluminium nitride films. These films were prepared by both DC- and RF-sputtering technique, and their structure and optical properties were compared

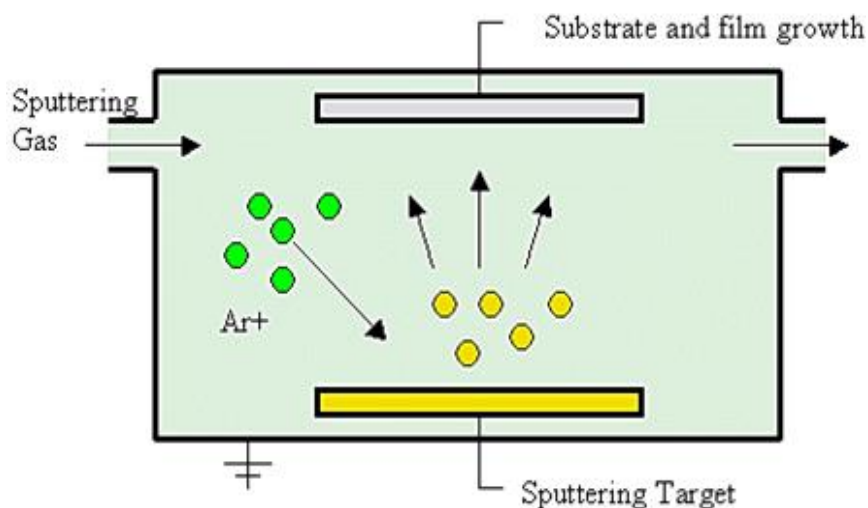


Fig. 1.7 Sputtering

1.6.2 CHEMICAL DEPOSITION TECHNIQUES

1.6.2.1 SOL-GEL TECHNIQUE

The sol-gel technique is broadly used for the synthesis of oxide materials. Sol-gel process is one of the famous wet-chemical methods. It works under lower-temperature processing and gives better homogeneity for multicomponent materials. The word “sol” means the formation of a colloidal suspension and ‘gel’ means the conversion of ‘sol’ to viscous gels or solid materials.

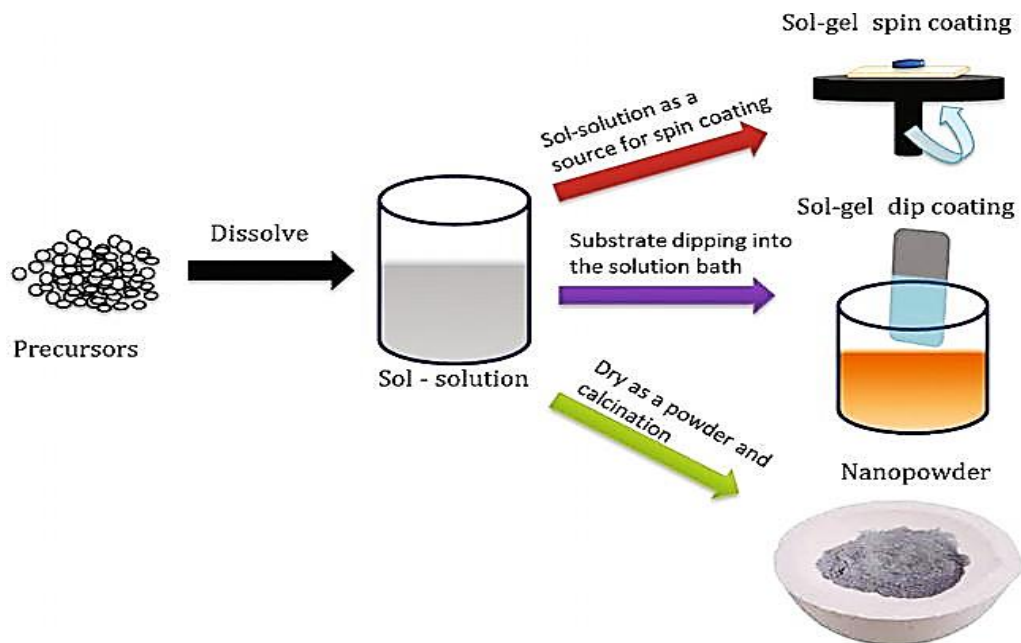


Fig. 1.8 Solgel technique

1.6.2.1.1 DIP-COATING TECHNIQUE

Dip-coating technique is almost used to fabricate transparent layers of oxides on a transparent substrate with a high degree of planarity and surface quality. Other substrates are also possible to use. Well-defined film thicknesses up to 1 μm can be deposited. Several additive layers can be superimposed. Criven described the dip-coating process in five stages: immersion, start-up, deposition, drainage, and

evaporation. Hence, the evaporation normally accompanies the start-up, deposition, and drainage steps as shown in Figure

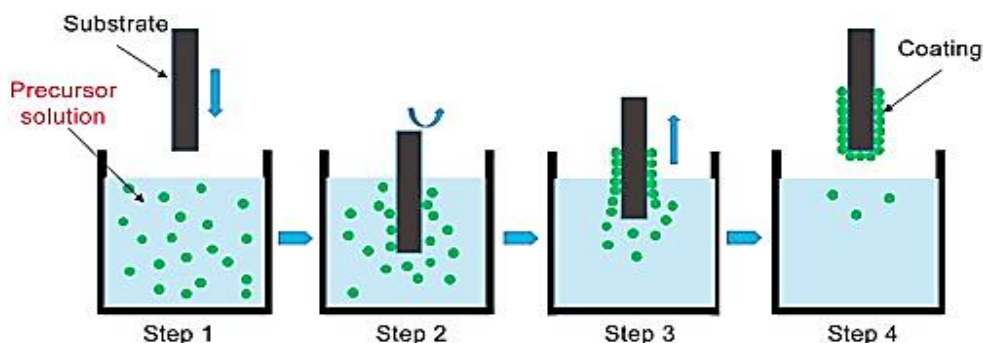


Fig. 1.9 Dip coating

1.6.2.1.2 SPIN-COATING TECHNIQUE

The solution is dripped onto a spinning substrate and spreads evenly. The spinning process is most suitable for the coating. Spin coating is a procedure used to deposit uniform thin films onto flat substrates. Usually a small amount of coating material is applied on the center of the substrate, which is either spinning at low speed or not spinning at all. The substrate is then rotated at speed up to 10,000 rpm to spread the coating material by centrifugal force. A machine used for spin coating is called a spin coater, or simply spinner. Rotation is continued while the fluid spins off the edges of the substrate, until the desired thickness of the film is achieved. The applied solvent is usually volatile, and simultaneously evaporates. The higher the angular speed of spinning, the thinner the film. The thickness of the film also depends on the viscosity and concentration of the solution, and the solventing of small disks or lenses but is not very economical.

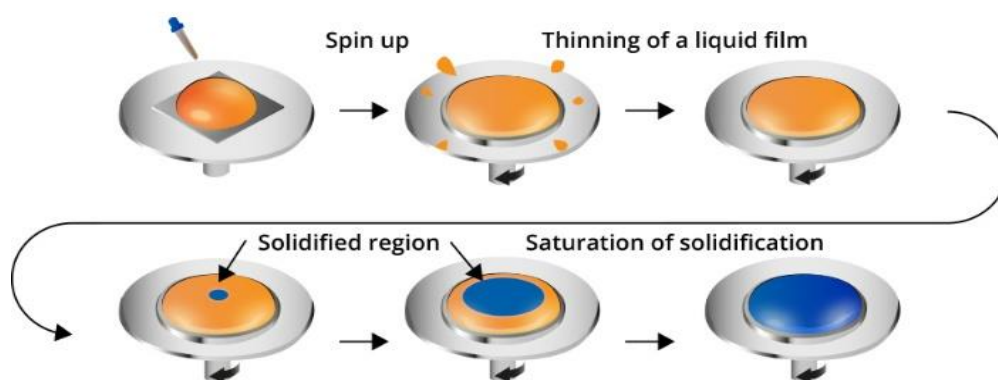


Fig. 1.10 Spin coating

1.6.2.2 CHEMICAL BATH DEPOSITION TECHNIQUE

Chemical bath deposition method is also known as solution growth technique or controlled precipitations. It is the oldest method to deposit films on a substrate. Solution growth technique is mostly used to prepare chalcogenide films as well as metal oxide films. Also, the deposition can be performed at lower temperatures. In the solution growth method, the precursor solution of metal ions must be complexed by ligands. The complex solution is almost obtained with ammonia solution, triethanol amine, ethylene-diamine-tetraacetic acid (EDTA), citric acid, and so on. When the complexation is completed, the addition of the anions should take place. These anions come from the thiourea, thioacetamide, thiosulfate, and sodium Sulfide solutions as sources of sulfur anions or selenourea and sodium selenosulfate for selenium anions to deposit the chalcogenides. Substrates are put in vertical, horizontal, or specific position inside the solution and left until the desired film thickness is obtained. The deposition of oxide films is quite different than chalcogenides. After making the complexation by controlling the pH value, the substrate is immersed in the solution under the desired temperature varied in the range 60°–100 °C to deposit in most cases the metal hydroxide films. The hydroxide film can then be transferred to oxide by the annealing process.

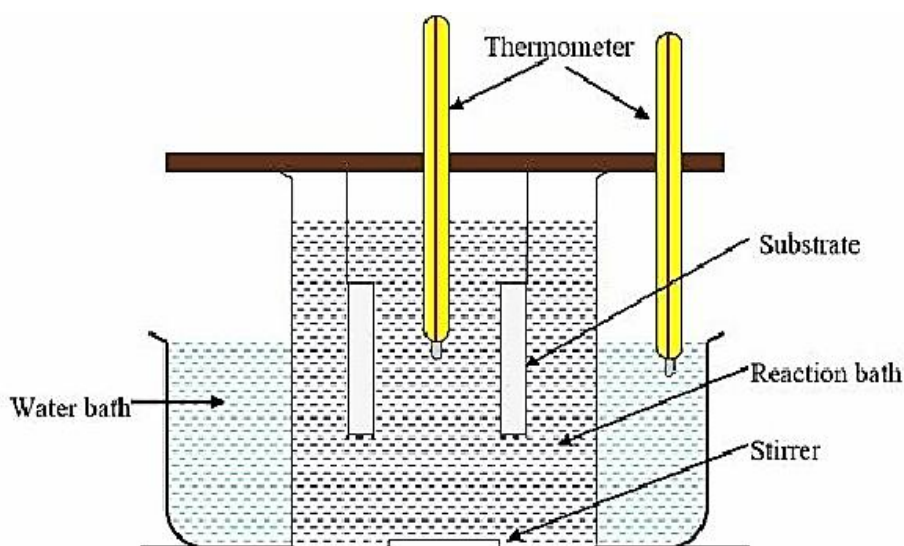


Fig. 1.11 Chemical bath deposition technique

CHAPTER 2

LITERATURE SURVEY

1. 'Synthesis of SnO₂ Thin Layer with a Doping Fluorine by Sol-Gel Spin Coating Method' Lalu Mulyadi^{1*}, Aris Doyan¹, Susilawati¹, Syamsul Hakim¹
¹Master of Science Education Program, University of Mataram, Lombok, West Nusa Tenggara, Indonesia May 21st ,

Abstract: A thin layer of tin oxide with doping Fluorine was synthesized using the sol-gel spin coating method. The synthesis aims to determine the quality of thin layers formed based on temperature variations and the number of layers. The basic material used is SnCl₂.2H₂O, while the doping material used is NH₄F with variations in concentrations of dopants 0, 5, 10, 15, 20 and 25%. The substrate used is glass with a size of 10 x 10 x 3 mm. The synthesis of the thin layer includes substrate preparation, sol-gel making, thin film making, and heating process. At this stage SnO₂:F is deposited on a glass substrate with sol-gel spin coating technique at the concentration of sol 1 M with doping levels of Fluorine 0, 5, 10, 15, 20 and 25%, and treated with maturation for 24 hours. Making a thin layer using a spin coater at a speed of 2000 rpm for 3 minutes. The layer made consists of one layer, two layers, three layers and four layers.

2. 'Synthesis of SnO₂ Thin Coatings by Indium and Aluminum Mixed Doping using the Sol-Gel Spin-Coating Technique' Haris Munandar^{1*} , Aris Doyan^{1,2}, Susilawati^{1,2} ¹Master of Science Education Program, University of Mataram, Lombok, West Nusa Tenggara, Indonesia, June 9th, 2020

Abstract: This research succeeded in creating a thin layer of SnO₂ and SnO₂: In+Al through a synthesis process with the sol-gel spin-coating technique on a glass substrate. The manufacture of this thin layer uses the basic material SnCl₂.2H₂O, and the doping material InCl₃.4H₂O and AlCl₃. This thin layer is made with variations in doping concentration, number of layers, and heating temperature. The results of the synthesis of SnO₂: In+Al films show that the thin film formed is more transparent when the doping concentration and the number of layers is increased. Meanwhile, the thin layer that forms is increasingly not transparent when heated at higher temperatures.

3. 'Evaluation of Bulk and Surfaces Absorption Edge Energy of Sol-Gel-Dip-Coating SnO₂ Thin Films'

Emerson Aparecido Floriano^a, Luis Vicente de Andrade Scalvia^{a,b}, Julio Ricardo Sambranoc, Viviany Geraldob, October 20 2010

Abstract: The absorption edge and the bandgap transition of sol-gel-dip-coating SnO₂ thin films, deposited on quartz substrates, are evaluated from optical absorption data and temperature dependent photoconductivity spectra. Structural properties of these films help the interpretation of bandgap transition nature, since the obtained nanosized dimensions of crystallites are determinant on dominant growth direction and, thus, absorption energy. Electronic properties of the bulk and (110) and (101) surfaces are also presented, calculated by means of density functional theory applied to periodic calculations at B3LYP hybrid functional level. Experimentally obtained absorption edge is compared to the calculated energy band diagrams of bulk and (110) and (101) surfaces

4. 'The thickness effect to optical properties of SnO₂ thin film with doping fluorine'

Susilawati^{1,2*}, A Doyan^{1,2}, L Mulyadi¹, S Hakim¹ and M Taufik²
¹Master of Science Education Program, University of Mataram, Lombok, West Nusa Tenggara, Indonesia

Abstract : Synthesis of SnO₂:F thin layer was grown using the sol-gel spin coating method on a glass substrate with various layers (one to four layers). The purpose of the synthesis was to determine the optical properties of thin layers including transmittance, absorbance, energy bandgap, and activation energy. The optical properties of the layers were characterized using UV-Vis spectrophotometers with a wavelength of 200-1100 nm. The results showed that at a wavelength of 300 nm the absorbance value decreased with an increasing number of layers. Absorbance values obtained for variations in layers (one to four layers) for the percentage of 95:5% and 75:25%, respectively 3.59-2.85 and 4.30-3.42, while the transmittance value decreased, namely 96.8-79.6% and 98.3-81.1%. Besides, the energy bandgap obtained decreases with an increasing number of layers. The energy bandgap decreased from 3.69-3.56 eV and 3.59-3.42 eV for direct allowed, while 4.00-3.91 eV and 3.96-3.83 eV for indirect allowed. Activation energy decreased from 0.23-0.07 eV and 4.35-1.43 eV.

5. 'Deposition of Tin Oxide Thin Film by Sol-Gel Dip Coating Technique and Its Characterization' B. R. Aswathy a) , K. Vinay, M. Arjun, P. K. Manoj T K M
College of Arts and Science, Kollam, Kerala, India

Abstract: Tin oxide (SnO_2) thin films were deposited on glass substrate using inorganic precursor by sol gel dip coating technique. The structural studies of the films were obtained by X-ray diffraction technique and the data showed that the synthesized tin oxide films have triclinic structure with preferred orientation along $(-2, 1, 0)$ and $(-4, 2, 0)$ plane. Optical studies revealed that the film having more thickness shows better transmission about 92% in the visible region and optical band gap energy increases to 2.93eV due to Moss-Burstein effect. The presence of tin and oxygen in the samples were confirmed with characteristic vibrational mode of Sn–O in the region $430\text{--}482\text{ cm}^{-1}$ and $669\text{--}674\text{ cm}^{-1}$ using FTIR spectroscopy. Photoluminescence spectra shows the presence of emission in the visible region depends on thickness of the film. This study suggests that the sol-gel dip coating method is the best method for fabricating highly pure, transparent and homogenous mixed valence phase of tin oxide thin film and further studies may be required to tailor electrical and optical properties of the films suitable for various optoelectronic applications.

6. 'Synthesis of Tin Oxide Thin Film and Effect of Number of Coating on Transmittance and Film Thickness' Sumanta Kumar Tripathy 1,*, P. V. Rajeswari 1 and Bhabani Prasad Hota 2
1 GVP College of Engineering (Autonomous), Madhurawada, Visakhapatnam, A.P., India 2 Godavaris Mahavidyalaya, Banpur, Khurda, Odisha, India

Abstract: This paper studies the synthesis of semiconducting tin oxide thin film on a glass substrate by dip coating method using Tin(II) chloride as precursor and methanol as solvent. The optical properties were studied by Elco-UV/VIS Spectrophotometer, Model- SL-159. The thickness of the film has been calculated from the interference pattern of the transmission spectrum (wavelength Vs. transmission curve) for each coat. It is concluded that thickness of the thin film increases nearly linearly with the number of coating. The effect of multiple applications on transmittance is also studied.

7. Adjimi, A, Zeggar, M.L, Attaf, N. and Aida, M.S. (2018) '**Fluorine-Doped Tin Oxide Thin Films Deposition by Sol-Gel Technique**'. Journal of Crystallization Process and Technology, 8, 89-106.

Abstract: In the present work, undoped (SnO₂) and fluorine-doped tin oxide (FTO) thin films were prepared by sol-gel process using a solution composed of (SnCl₂, H₂O), (NH₄F), and ethanol mixture. The fluorine concentration effect on structural, optical and electrical properties of SnO₂ films is investigated. The electrical properties of FTO films prepared by sol gel remain relatively lower than the ones deposited by other techniques. In present paper, we try to elucidate this difference. Films composition and the FTIR analysis, of films and formed precipitate during film growth, indicate that few amounts of fluorine are incorporated in SnO₂ network, most of fluorine atoms remain in the solution. The films resistivity is reduced from 1.1 Ω·cm for undoped films to 3×10^{-2} Ω·cm for 50 wt.% doped FTO, but remains higher than the reported ones in the literature. This high resistivity is explained in terms of fluorine bonding affinity in the solution

8.'**Electrical Characterization of Tin Oxide Thin Films Prepared by Dip Coating Technique**' E. Sivasenthil¹ , V. Senthilkumar² Research Scholar, Department of Physics, Karpagam University, Coimbatore, Tamil Nadu, India¹ Head and Associate Professor, Department of Physics, Karpagam University, Coimbatore, Tamil Nadu, India²

Abstract: The influence of bath temperature on tin oxide Nano layers on the surface of glass substrate by sol-gel dip coating method was investigated. The bath temperature was varied from 313 K to 373 K in steps of 20 K. The deposited films were annealed at 673 K. These films were characterized by dc conductivity measurements. The dc electrical conductivity was measured in the temperature range of 303-403 K and was found to increase with temperature. The results indicated that the material could be used for solar and laser applications.

9. '**The effect of various precursors and solvents on the characteristics of fluorine-doped tin oxide conducting glass fabricated by ultrasonic spray pyrolysis**' Akhmad Herman Yuwono^{1,2*} , Tri Arini^{1,3}, Latifa Hanum Lalasari³ , Nofrijon Sofyan^{1,2}, Ghiska Ramahdita^{1,2}, Andaradhi Nararya¹ , F. Firdiyono³ ,

Lia Andriyah³, Achmad Subhan⁴, Puspipetek Serpong, Cisauk, Banten 15314, Indonesia
⁴Research Center for Physics, Indonesian Institute of Science, Indonesian, October 2017.

Abstract: In this work, FTO glass has been fabricated by the ultrasonic spray pyrolysis technique with different precursors, tin (II) chloride dihydrate ($\text{SnCl}_2 \cdot 2\text{H}_2\text{O}$) and anhydrous tin (IV) chloride (SnCl_4), as well as different solvents, i.e. ethanol and methanol. For both conditions, ammonium fluoride (NH_4F) was used as the doping compound. The resulting thin films were characterized by use of a scanning electron microscope (SEM), x-ray diffraction (XRD), ultraviolet-visible (UV-Vis) spectroscopy and a four-point probe test. The results of the investigation show that the highest transmittance of 88.3% and the lowest electrical resistivity of $8.44 \times 10^{-5} \Omega \cdot \text{cm}$ were obtained with the FTO glass processed with 20 minutes of spray pyrolysis deposition and 300°C substrate heating, using SnCl_4 as the precursor and methanol as the solvent.

10.'Structural, Morphological and Optical Characterization of $\text{SnO}_2:\text{F}$ thin films prepared by Chemical spray Pyrolysis' Salam Amir Yousif, Jenan Mohamed Abass
Department of Physics, College of Education, Al-Mustansiriyah University, Baghdad, Iraq

Abstract: Fluorine doped tin oxide (FTO) films were successfully prepared on glass and quartz substrate at a substrate temperature equal to for different fluorine doping (0, 0.05, 0.1, 0.15) by a homemade spray pyrolysis technique. The spray solution prepared from tin tetrachloride pentahydrate dissolved in distilled water at concentration and ammonium fluoride was added into the solution for fluorine doping. X-ray diffraction patterns of the spray-deposited ($\text{SnO}_2:\text{F}$) films for different fluorine doping show that all the diffractograms contain the characteristic SnO_2 orientations. The matching of the observed and standard d-values confirm that the deposited films are of tin oxide with tetragonal structure and the films are polycrystalline with (110) as a preferred growth orientation. The surface morphology of thin film has been examined by atomic force microscopy (AFM). The average transmittance in the visible region (at 550 nm) has been found (40 %, 47 %, 52 %, 59 %, 61 %) for the fluorine doping (0, 0.05, 0.1, 0.15, 0.2) respectively.

CHAPTER 3

AIM AND SCOPE OF THE PRESENT INVESTIGATION

Aim of this project is to Synthesis fluorine doped tin oxide thin films by sol-gel spin coating method. We aimed to understand the difference in efficiency of pure and fluorine doped SnO_2 . To synthesize the fluorine doped SnO_2 thin film and to analyse the characteristics of the film. We choose the sol-gel technique for the preparation of FTO thin film to reduce the cost and time required for the preparation. Synthesis was mainly focused on the solar cell application. Structural characteristics were determined by Raman effect. Optical characteristics was investigated using a UV-Visible spectrometer. Electrical characteristics was studied using Hall effect measurements.

The dawn of 21st century has seen the beginning of the applications of thin film technology in commercial products. Over time, the applications of thin films have grown exponentially and have become an integral part of both industrial and research processes. Thin films are considered as backbone for advanced applications in the various fields such as optical devices, environmental applications, telecommunications devices, energy storage devices, and so on. Applications of thin films may be grouped under the following generic areas: Data storage, Thin film solar cells, Optoelectronic devices and optical coating, Thin film lithium ion batteries. As a result, we are using fluorine doped tin oxide thin film to improve the efficiency of the solar cell.

CHAPTER 4

MATERIALS, METHODOLOGY & EXPERIMENTAL PROCEDURE

4.1 MATERIALS

4.1.1 Stannous Chloride

Tin (II) chloride, also known as stannous chloride, is a white crystalline solid with the formula SnCl_2 . It forms a stable dihydrate, but aqueous solutions tend to undergo hydrolysis, particularly if hot. SnCl_2 is widely used as a reducing agent (in acid solution), and in electrolytic baths for tin-plating.

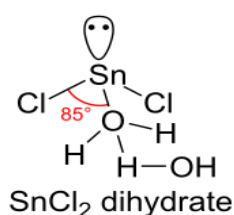
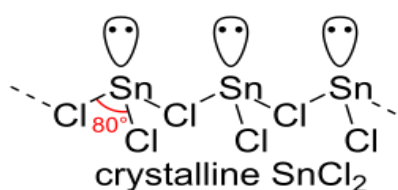


Fig. 4.1 Stannous chloride

SnCl_2 has a lone pair of electrons, such that the molecule in the gas phase is bent. In the solid state, crystalline SnCl_2 forms chains linked via chloride bridges as shown. The dihydrate is also three-coordinate, with one water coordinated on to the tin, and a second water coordinated to the first. The main part of the molecule stacks into double layers in the crystal lattice, with the "second" water sandwiched between the layers.

IUPAC name : Tin(II)chloride

Synonyms : Salt of tin, Stannous chloride dehydrate

Molecular formula : $\text{SnCl}_2 \cdot 2\text{H}_2\text{O}$

Molecular weight : 225.63

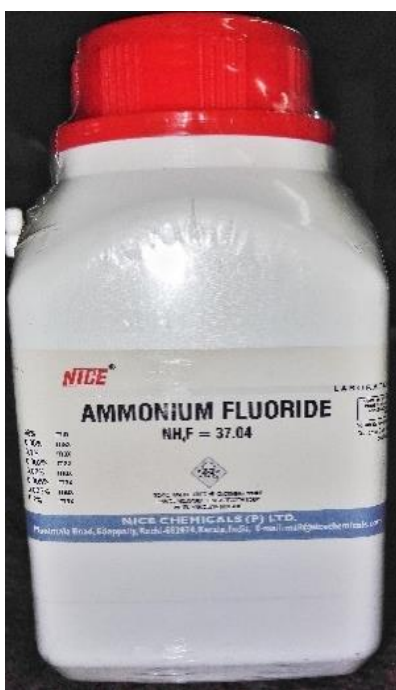
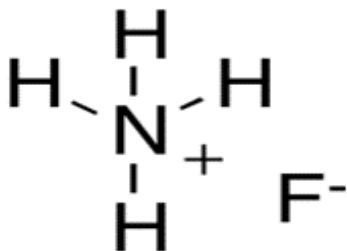
Melting point : 37 - 38°C/lit

Boiling point : 652°C/lit

Density : 2.71 g/cm³

4.1.2 Ammonium Fluoride

Ammonium fluoride is the inorganic compound with the formula NH_4F . It crystallizes as small colourless prisms, having a sharp saline taste, and is highly soluble in water. Like all fluoride salts, it is moderately toxic in both acute and chronic overdose.



IUPAC name : Ammonium chloride

Molecular formula : NH_4Cl

Molecular mass : 17.031 g/mol

Density : 0.73 kg/m³

Boiling Point : -33.34 °C

Melting Point : -77.73 °C

Fig. 4.2 Ammonium fluoride

Ammonium fluoride adopts the wurtzite crystal structure, in which both the ammonium cations and the fluoride anions are stacked in ABABAB... layers, each being tetrahedrally surrounded by four of the other. There are $\text{N}-\text{H}\cdots\text{F}$ hydrogen bonds between the anions and cations. This structure is very similar to ice, and ammonium fluoride is the only substance which can form mixed crystals with water.

4.1.3 Ethanol

ethanol, also called ethyl alcohol, grain alcohol, or alcohol, a member of a class of organic compounds that are given the general name alcohols; its molecular formula is C_2H_5OH . Ethanol is an important industrial chemical; it is used as a solvent, in the synthesis of other organic chemicals, and as an additive to automotive gasoline (forming a mixture known as a gasohol). Ethanol is also the intoxicating ingredient of many alcoholic beverages such as beer, wine, and distilled spirits.

IUPAC name : Ethanol

Synonyms : spirits of wine

Molecular formula : CH_3CH_2OH

Molecular mass : 46.069 g/mol

Melting point : $-114.14^{\circ}C$

Boling point : $78.24^{\circ}C$

Density : 0.7893 g/cm³

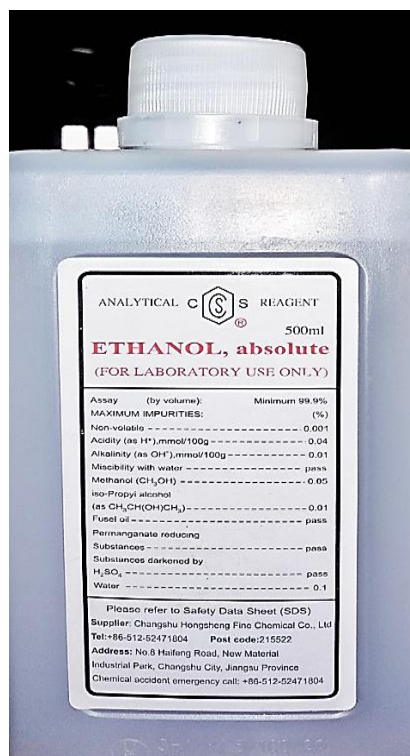
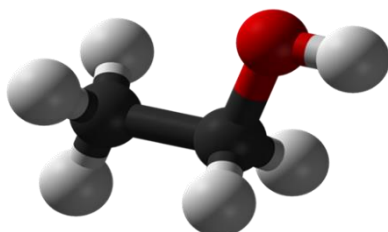
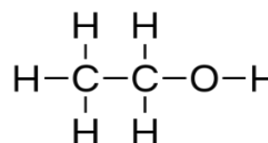


Fig. 4.3 Ethanol

Ethanol (ethyl alcohol, CH_3CH_2OH) is one of a group of chemical compounds (alcohols) with molecules that contain a hydroxyl group (OH) bonded to a carbon atom. Ethanol is produced through the fermentation of agricultural products such as sugarcane, corn, and manioc, among others. Ethanol, also called alcohol, ethyl alcohol and grain alcohol, is a clear, colourless liquid and the principal ingredient in alcoholic beverages like beer, wine or brandy.

4.2 METHODOLOGY

4.2.1 Spin coating

Spin coating is a method of producing uniform thin films using centrifugal force as the method of deposition. In a typical process, a uniformly planar substrate is secured on a spindle and a liquid precursor/nanoparticle solution is dispensed via a syringe onto the centre of the workpiece.

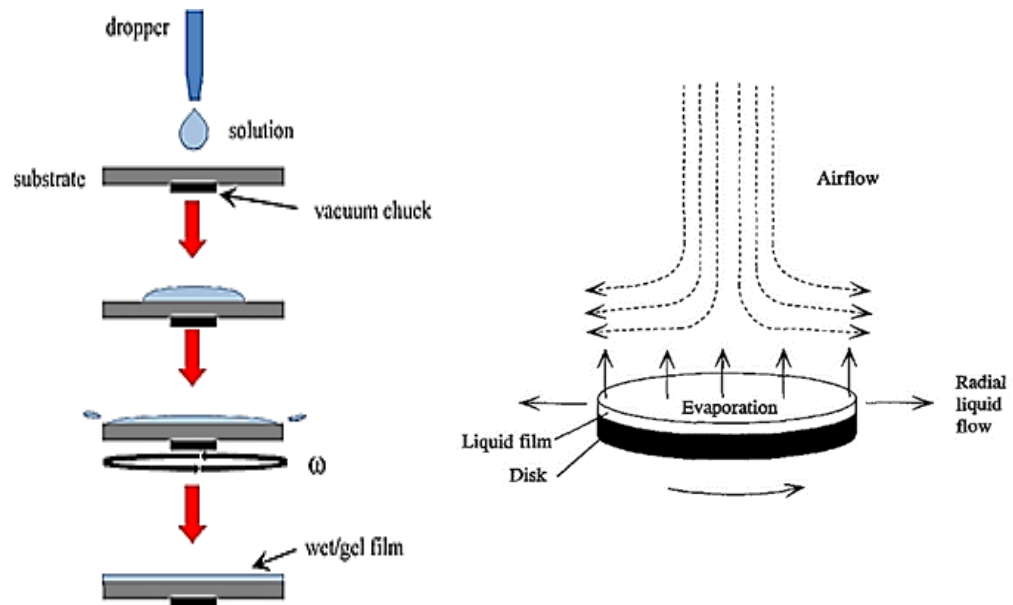


Fig. 4.4 Spin coating procedures

This substrate is then centripetally accelerated which causes the liquid to spread across the surface via centrifugal force. Excess material is thrown off the edge of the rotating substrate, leaving a uniform thin film on the surface. Spin coating is a common technique for applying thin films to substrates. When a solution of a material and a solvent is spun at high speeds, the centripetal force and the surface tension of the liquid together create an even covering. After any remaining solvent has evaporated, spin coating results in a thin film ranging from a few nanometres to a few microns in thickness.

Spin coating is used in a wide variety of industries and technology sectors. Its primary advantage of spin coating over other methods is its ability to quickly and easily produce very uniform films. Spin-coating comprises two major processes

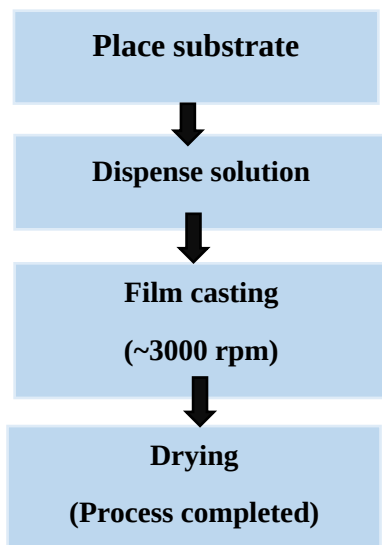


Fig.4.5 Spin coating flow chart

which take place simultaneously: radial liquid flow, which is a consequence of the centrifugal force, and evaporation of the solvent, both these two processes result in a decrease of the thickness of the liquid film. The radial flow behaviour of the liquid follows from a force balance between the centrifugal force and the shear force.

Spin coating has been used for several decades for the application of thin films. A typical process involves depositing a small puddle of a fluid resin onto the centre of a substrate and then spinning the substrate at high speed (typically around 3000 rpm). Centripetal acceleration will cause the resin to spread to, and eventually off, the edge of the substrate leaving a thin film of resin on the surface. Final film thickness and other properties will depend on the nature of the resin (viscosity, drying rate, percent solids, surface tension, etc.) and the parameters chosen for the spin process. Factors such as rotational speed, acceleration, and fume exhaust contribute to how the properties of coated films are defined. One of the most important factors in spin coating is repeatability. One advantage to spin coating thin films is the uniformity of the film thickness. Owing to self-leveling, thicknesses do not vary more than 1%. However, spin coating thicker films of polymers and photoresists can result in relatively large edge beads whose planarization has physical limits.

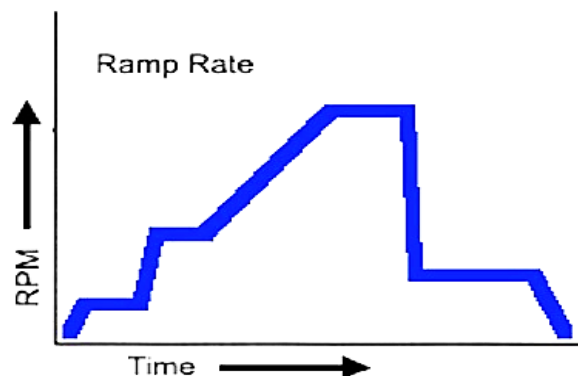


Fig. 4.6 Model RPM v/s Time graph

4.3 EXPERIMENTAL TECHNIQUES

Experimental Procedure

In this study we used three main ingredients, Tin chloride dihydrate ($\text{SnCl}_2 \cdot 2\text{H}_2\text{O}$) with molar mass of 225.63 grams per mole and purity 95%. 20 ml Ethanol with molar mass of 46.07 gram per mole and purity 99% is used as solvent and the material for doping is the Ammonium fluoride with molar mass of 37.04 grams per mole.

The substrate used is the glass slide and its preparation is done by inserting the glass substrate in a solution of potassium dichromate and dilute hydrochloric acid in a beaker and kept it for 20 hours. Later the glass substrates taken out and kept inside Millipore water in a beaker and this setup is Sonicated with sonicator for 15 minutes. After that the glass substrates are placed in the oven at around 100 degree Celsius for 3 hours.

Tin chloride dihydrate and ammonium fluoride is weighed using chemical balance corresponding to the calculated percentages and then dissolved in 20 ml ethanol. This solution is made homogeneous by stirring under magnetic stirrer for 2 hours. And the solution is left 24 hours for ageing. After the aging of 24 hours the solgel forms, then the thin layer is synthesized by spin coating. In spin coating solgel dripped on the glass substrate and it rotated using the spin coater at a speed of 2000 RPM for 3 minutes. After the spinning the substrate dried in room temperature and then annealed using the furnace with temperature around 150 degree Celsius for 1 hour.

Doping percentage (%)	$\text{SnCl}_2 \cdot 2\text{H}_2\text{O}$ (gram)	NH_4F (gram)
100:0	4.515	0
90:10	4.063	0.074

Table 1 Doping Percentages



Fig.4.7 glass substrates in potassium dichromate+HCl solution

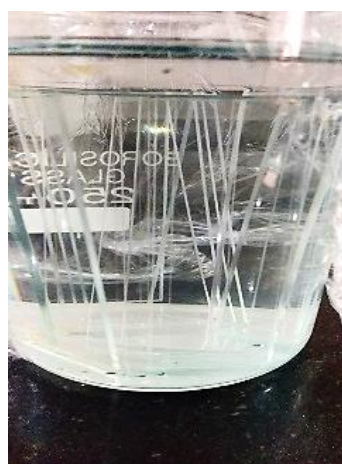


Fig. 4.8 glass substrates in Millipore water

Sonicator: Sonication it is the act of applying sound energy to agitate particles in a sample. Ultrasonic frequency is a usually used, leading to the process also known as ultrasonication or ultra-sonication. Mechanism used in ultrasonic cleansing using particles adhering to surfaces. Cleaning works through high frequency sound waves transmitted through liquid to Scrub clean the surface of immersed parts



Fig. 4.9 Sonicator

Hot air oven: It's a type of dry heat sterilization. Electrical devices which use dry heat sterilization. Use thermostat to control the temperature the double walled insulation keeps the heat in and conserve energy the inner layer being a poor conductor and out layer being metallic.



Fig. 4.10 Hot air oven



Fig.4.11 Weighing the materials using chemical balance

Magnetic stirrer: A magnetic stirrer or magnetic mixer is a laboratory device that employs a rotating magnetic field to cause a stir bar immersed in a liquid to spin very quickly, thus stirring it. A magnetic stirrer is an electromechanical device that mixes with the help of an external magnetic field that rotates a stir bar placed in the mixture. Stir bar rotates at different speeds and can mix volumes up to one liter.



Fig. 4.12 Stirring using magnetic stirrer



Fig.4.13 Sol-gel formation



Fig.4.14 Thin film prepared using spin coater



Fig.4.15 RPM Vs Time graph



Figure.4.16 Pure SnO₂ thin film (100:0)



Fig.4.17 Fluorine doped SnO₂ thin film of doping ratio 90:10

CHAPTER 5

CHARACTERISATION

5.1 RAMAN SPECTROSCOPY

Raman spectroscopy is a spectroscopic technique typically used to determine vibrational modes of molecules, although rotational and other low-frequency modes of systems may also be observed. Raman spectroscopy is commonly used in chemistry to provide a structural fingerprint by which molecules can be identified. It relies upon inelastic scattering of photons, known as Raman scattering. A source of monochromatic light, usually from a laser in the visible, near infrared, or near ultra violet range is used, although X-rays can also be used. The laser light interacts with molecular vibrations, phonons or other excitations in the system, resulting in the energy of the laser photons being shifted up or down. The shift in energy gives information about the vibrational modes in the system. Infrared spectroscopy typically yields similar yet complementary information.

Interpretation of Raman spectra: There are a number of approaches which can be used to interpret Raman spectra, including the methods described below.

By identifying functional groups within molecules: The vibrations of certain distinct subunits of a molecule, called its functional groups, will appear in a Raman spectrum at characteristic Raman shifts. Such a shift is similar for all molecules containing the same functional group. These signals are particularly useful when monitoring reactions which involve these functional groups (oxidation, polymerization, etc.), since they provide a direct measure of the progress during the reaction.

Using the characteristic "fingerprint region": Apart from the molecular vibrations of specific functional groups, vibrations of the molecular scaffolding (skeletal vibrations) can be detected in a Raman spectrum. Skeletal vibrations are usually found at Raman shifts below 1500 cm^{-1} and have a substance-specific, characteristic pattern. This region, often referred to as the "fingerprint" region of a substance, is the most important part of the spectrum for identification purposes.

5.2 UV - VISIBLE SPECTROSCOPY

UV-Vis spectroscopy is an analytical technique that measures the amount of discrete wavelengths of UV or visible light that are absorbed by or transmitted through a sample in comparison to a reference or blank sample.

UV spectroscopy or UV–visible spectrophotometry refers to absorption spectroscopy or reflectance spectroscopy in part of the ultraviolet and the full, adjacent visible regions of the electromagnetic spectrum. This means it uses light in the visible and adjacent ranges.

The Principle of UV-Visible Spectroscopy is based on the absorption of ultraviolet light or visible light by chemical compounds, which results in the production of distinct spectra.

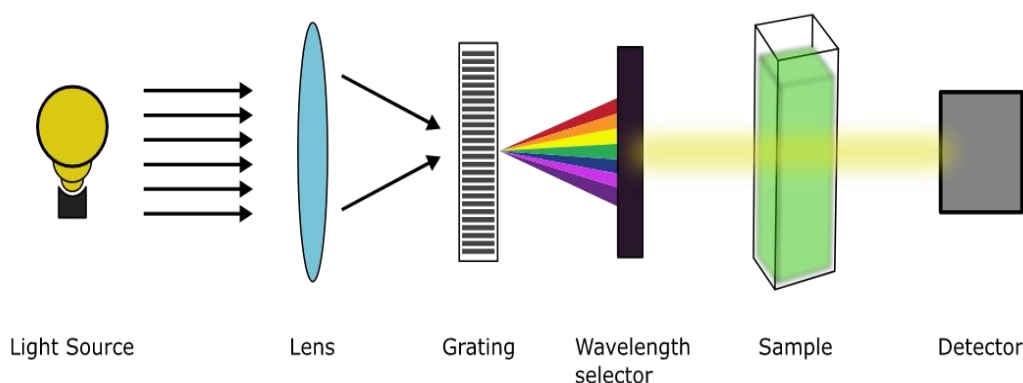


Fig.5.1 UV-Visible Spectroscopy

UV-visible spectroscopy exploits the wave-like nature of electrons and its interactions with electromagnetic radiation. UV-Vis spectroscopic instruments are used to identify, characterize, and quantify an extraordinary wide range of molecular compounds. It can be used for non-destructive measurements, such as determining the sugar, lipid, protein content of foodstuffs and for identifying medicinals.

When a material is irradiated with an electromagnetic wave, phenomena such as transmission, absorption, reflection, and scattering can occur. Absorption occurs when the energy of incoming light is equal to the energy difference (ΔE) between a molecule's ground and excited states. The excitation of an electron from the

ground state to an excited state is described as an electronic transition. The relationship between the energy difference and wavelength is described by the Planck equation.

$$E=h\nu=hc/\lambda$$

Where,

E is the energy required to promote an electron from the ground to excited state,

h is Planck's constant,

ν is the wavenumber,

c is the speed of light,

and λ is the wavelength.

The amount of light absorbed by the sample depends on the number of molecules interacted with. The more concentrated a sample is, the more molecules are present and the higher the absorbance. Likewise, the longer the pathlength of the cell, the greater the distance that the light travels through the sample, increasing the number of molecules interacted with and therefore the absorbance. To compare the absorbances of two solutions with either different concentrations or pathlengths, there needs to be a constant variable to normalize the data on. Additionally, to determine a sample's concentration by measuring absorbance, the cell pathlength and the strength of the electronic transition of the chromophore must be known. This constant or the probability of the electronic transition occurring is the molar absorptivity. Since molecules have different electronic transitions of varying strengths, the molar absorptivity will vary depending on the transition being probed and is therefore wavelength dependent.

5.3 HALL EFFECT

The Hall effect is when a magnetic field is applied at right angles to the current flow in a thin film where an electric field is generated, which is mutually perpendicular to the current and the magnetic field and which is directly proportional to the product of the current density and the magnetic induction.

Hall Effect is a process in which a transverse electric field is developed in a solid material when the material carrying an electric current is placed in a magnetic field that is perpendicular to the current. Hall Effect was discovered by Edwin Herbert Hall in 1879.

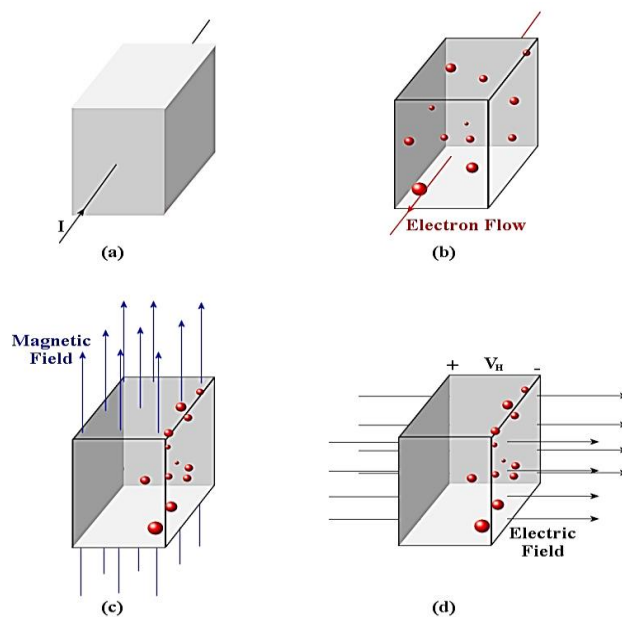


Fig.5.2 Hall effect

Principle of Hall Effect

The principle of Hall Effect states that when a current-carrying conductor or a semiconductor is introduced to a perpendicular magnetic field, a voltage can be measured at the right angle to the current path. This effect of obtaining a measurable voltage is known as the Hall Effect.

Theory: When a conductive plate is connected to a circuit with a battery, then a current starts flowing. The charge carriers will follow a linear path from one end of the plate to the other end. The motion of charge carriers results in the production

of magnetic fields. When a magnet is placed near the plate, the magnetic field of the charge carriers is distorted. This upsets the straight flow of the charge carriers. The force which upsets the direction of flow of charge carriers is known as Lorentz force. Due to the distortion in the magnetic field of the charge carriers, the negatively charged electrons will be deflected to one side of the plate and positively charged holes to the other side. A potential difference, known as the Hall voltage will be generated between both sides of the plate which can be measured using a meter.

The Hall voltage represented as V_H is given by the formula:

$$V_H = IB/qnd$$

Here,

I is the current flowing through the sensor

B is the magnetic Field Strength

q is the charge

n is the number of charge carriers per unit volume

d is the thickness of the sensor.

Hall Coefficient

The Hall Coefficient R_H is mathematically expressed as,

$$R_H = E/jB$$

Where j is the current density of the carrier electron, E_y is the induced electric field and B is the magnetic strength. The hall coefficient is positive if the number of positive charges is more than the negative charges. Similarly, it is negative when electrons are more than holes.

Van der pauw method:

The method was first propounded by Leo J. van der Pauw in 1958. The van der Pauw Method is a technique commonly used to measure the resistivity and the Hall coefficient of a sample. Its power lies in its ability to accurately measure the properties of a sample of any arbitrary shape, as long as the sample is approximately two-dimensional. The van der Pauw method employs a four-point probe placed around the perimeter of the sample, in contrast to the linear four point probe: this allows the van der Pauw method to provide an average resistivity of the sample, whereas a linear array provides the resistivity in the sensing direction.

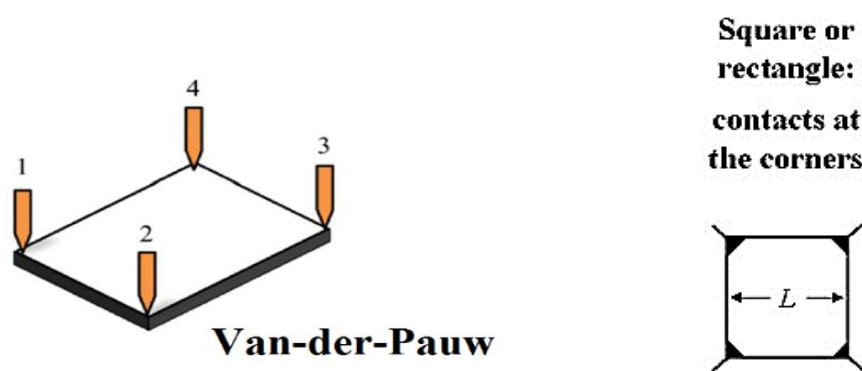


Fig.5.3 Van der pauw method

CHAPTER 6

RESULTS AND DISCUSSION

6.1 RAMAN SCATTERING ANALYSIS

Raman scattering is generally used to investigate the material crystallinity, structural defects and side effects of crystallites. Raman spectrum of undoped and F-doped SnO₂ thin films are shown in Figure.

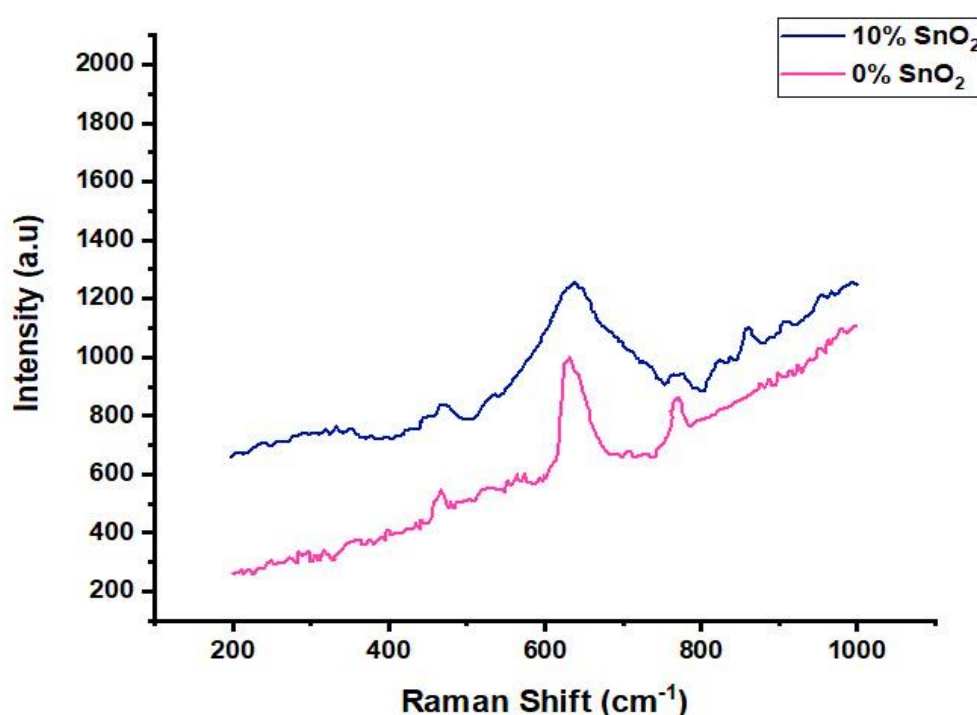


Figure.6.1 Raman spectrum of undoped(0%) and doped(10%) SnO₂

As can be seen, two fundamental Raman peaks located at 634 cm⁻¹, 475 cm⁻¹ in different spectrum, they are assigned to the symmetric and asymmetric stretching of Sn-O bonds. The appearance of these modes confirms the cassiterite tetragonal structure of SnO₂ as deduced from XRD analysis. A shift in the spectrum of doped SnO₂ towards the lower wave number, accompanied with broadening of the Raman bands is observed in SnO₂:F (10%), could arise from the strain in the crystallite and the disorder in the film network. This suggests that the fluorine incorporation is accompanied by the disorder formation in the film structure.

6.2 OPTICAL CHARACTERIZATION

The optical properties of thin films prepared with different fluorine-doped concentrations (0, 10) by spin coating technique on glass substrate have been investigated and the room temperature transmission and absorption spectra were measured in the range from (300 nm to 800 nm). The optical characteristics of SnO₂:F thin films were carried out using UV-Vis Spectrophotometer. The results obtained from these optical characteristics include Transmittance, Absorbance, Energy bandgap.

6.2.1 UV-VISIBLE SPECTROSCOPY

UV-visible spectroscopy is a useful technique for characterizing optical properties of thin films. The optical properties of doped and un-doped tin oxide films were studied using transmittance spectra, Absorbance spectra which was recorded in the range 300-800 nm at room temperature

6.2.1.1 TRANSMITTANCE

. Figure.6.2 shows the transmittance spectra of tin oxide thin films deposited on glass substrates. Both samples show high optical transmittance in the visible region. Optical interference is responsible for the many peaks in the transmission spectrum. The film is very transparent in the visible spectrum, with an average transmittance of up to 90-100%, and has a sharp ultraviolet cut off of around 290 nm. Because the size of grains and the surface texture of transparent films like SnO₂ have such a big impact on their transmission (Akgul, F et al.,2013).

Figure shows that the transmittance value in the wave range of 300-800 nm. The transmittance values for the undoped(pure) tin oxide. It is seen that the transmittance of the films increases with increasing fluorine dopant in the films, and the average transmittance in the visible region (at 550 nm) has been found 97%for the pure tin oxide. the colour of the undoped tin oxide thin film is milky white that turned slightly colourless When the doping concentration increased to 10%, which is in a good agreement with the transmittance spectrum.

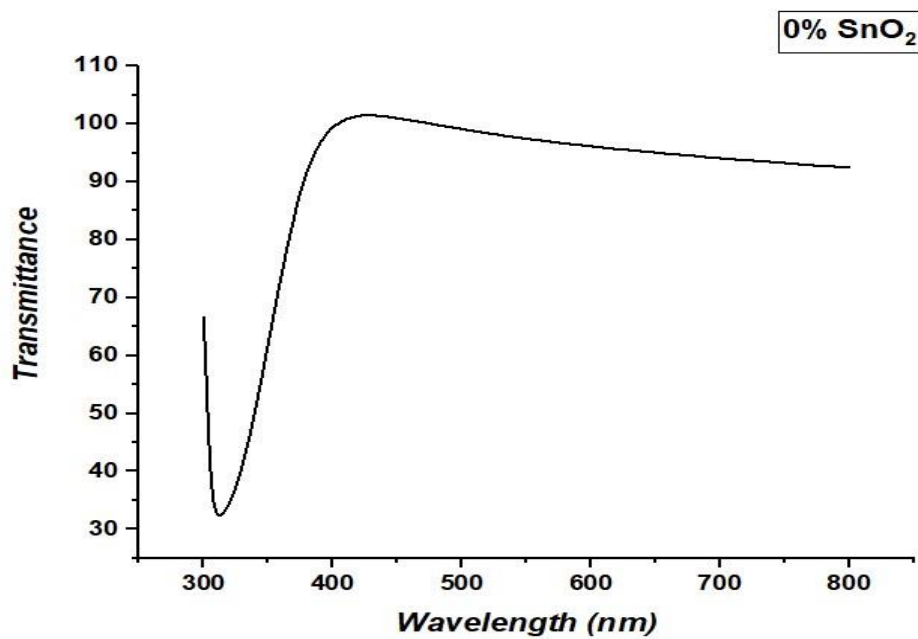


Fig.6.2 Transmittance graph of undoped SnO₂

6.2.1.2 ABSORBANCE

Graph of the relationship between the wavelength and absorbance of pure SnO₂ thin film deposited on glass substrate by spin coating method is shown in figure.6.3

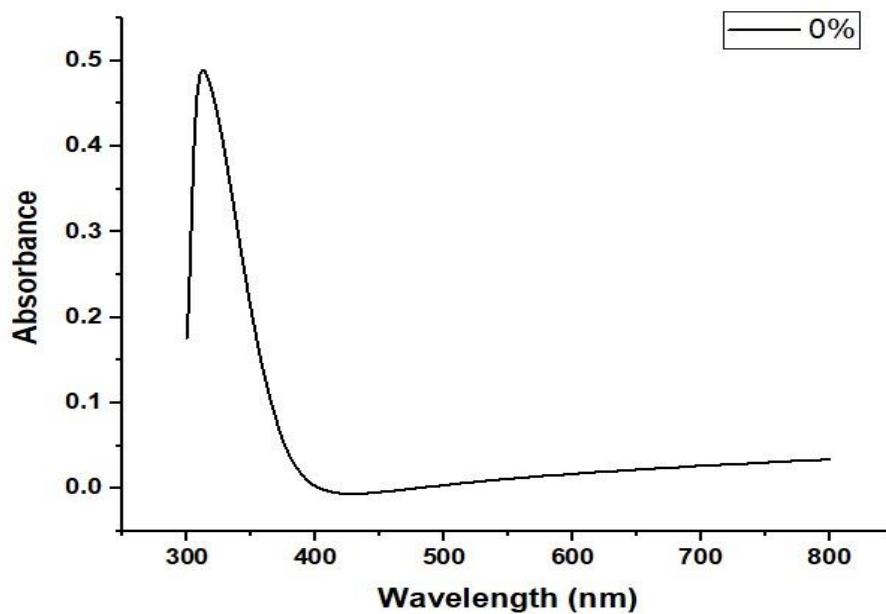


Figure.6.3 Thinfilm absorbance of un doped SnO₂

In this picture, we can see the difference in the absorbance value of SnO₂ thin layer for various wavelength. In the ultraviolet region with a wavelength of 300 nm, the absorbance value slightly peaks. After that increase the absorbance is decreased almost fairly throughout the visible region (400-800 nm). Figure.6.4. represents the optical absorption spectra of pure and Fluorine doped SnO₂ sol-gel. Based on the figure the absorbance of fluorine doped thin film is greater than that of undoped tin oxide.

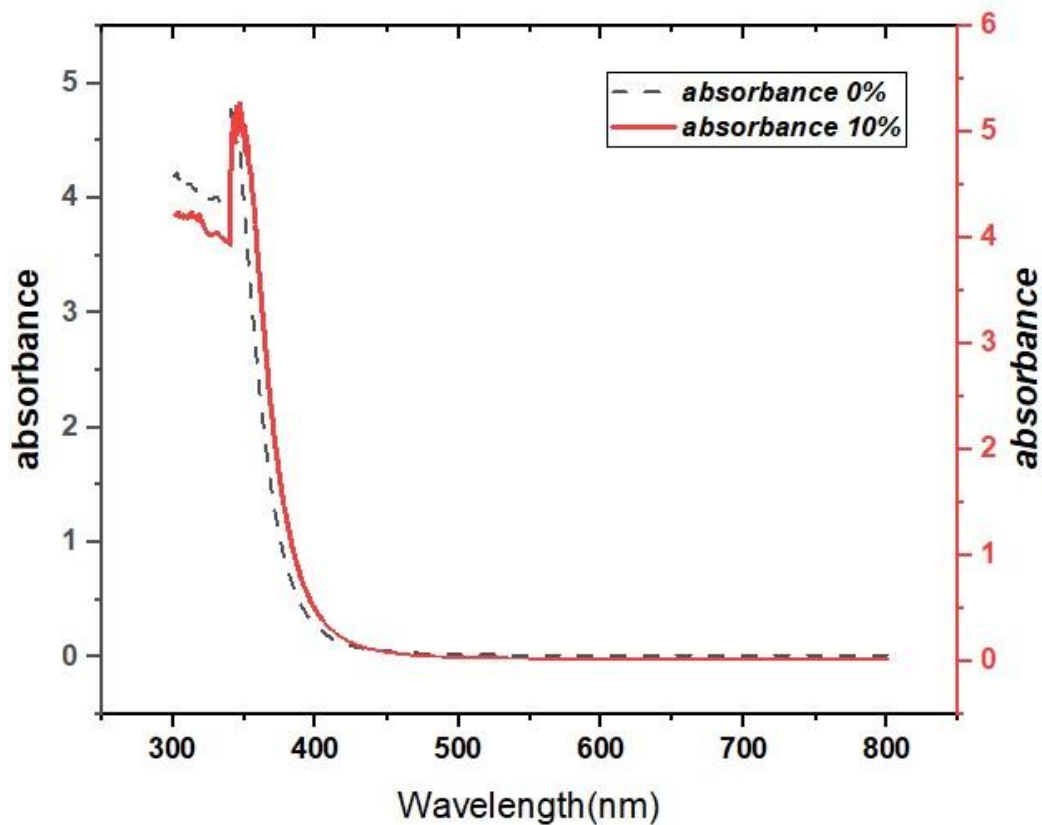


Figure.6.4 Sol-gel absorbance of pure (0%) and doped (10%) SnO₂

6.2.1.3 OPTICAL BAND GAP (E_g)

The optical bandgap is determined by extrapolating the linear part of the curve which intercepts the energy axis, E_g are found to be (3.39, 3.49, 3.33) eV for the (0%,0%, 10 %,) fluorine doping concentration respectively as shown in Figures.

In figure.6.5.As can be clearly seen the optical bandgap of FTO(10%) is 3.33eV which approximately in good agreement with the value(3.25).

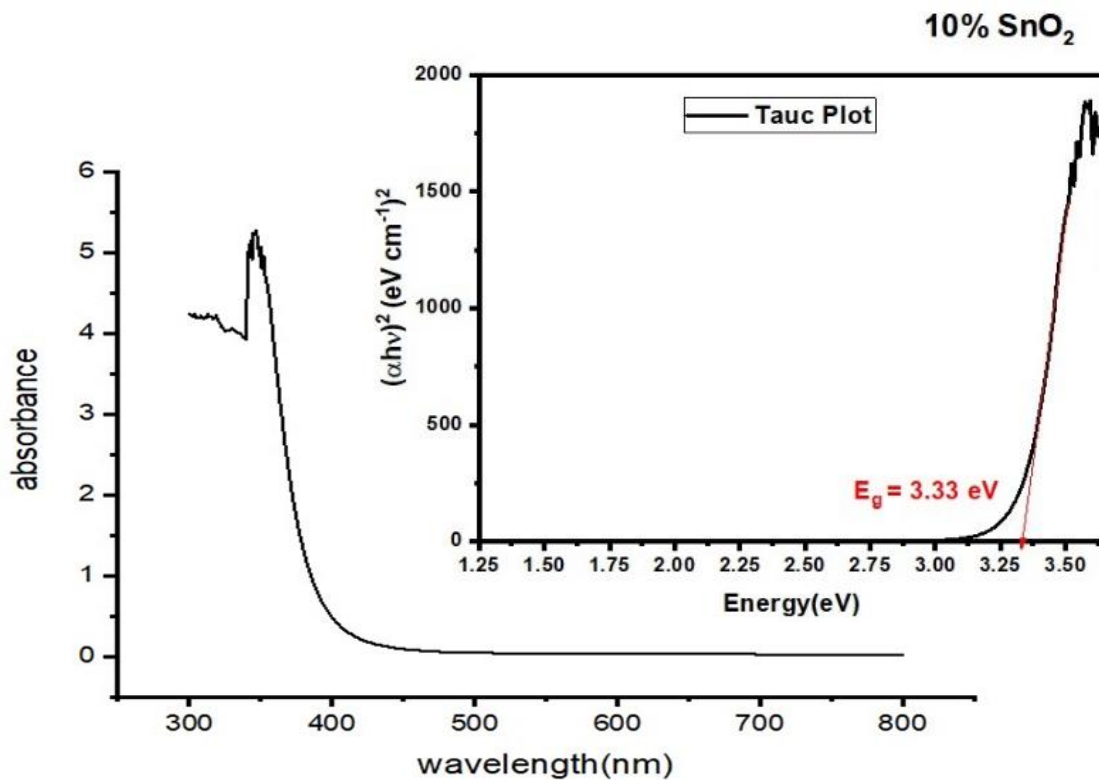


Figure 6.5 Optical absorption spectra for doped SnO₂ thin film. Inset – experimentally obtained direct bandgap

Figure 6.6 and figure 6.7 below shows that the bandgap energy value for the sol-gel and thin film pure SnO₂. The E_g values are 3.39 and 3.49 respectively. The obtained energy bandgap has decreased with an increased percentage of fluorine doping. Also, the presence of fluorine dopants causes the bandwidth built up by localization conditions in each film to be greater. The smaller the bandgap energy value possessed by the thin film, the easier it will be for electrons to move from the valence band to the conduction band. This results in the quality of a film being better used as a semiconductor material.

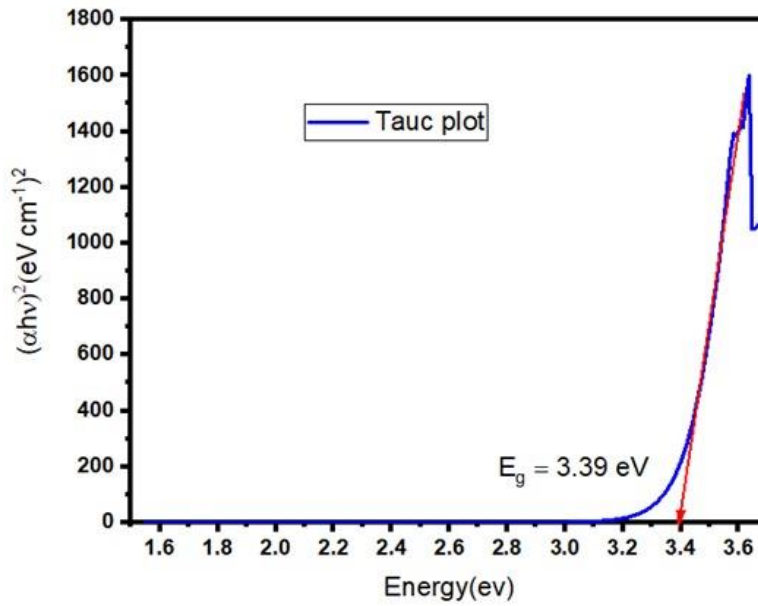


Fig. 6.6 optical band gap of undoped SnO₂ thin film

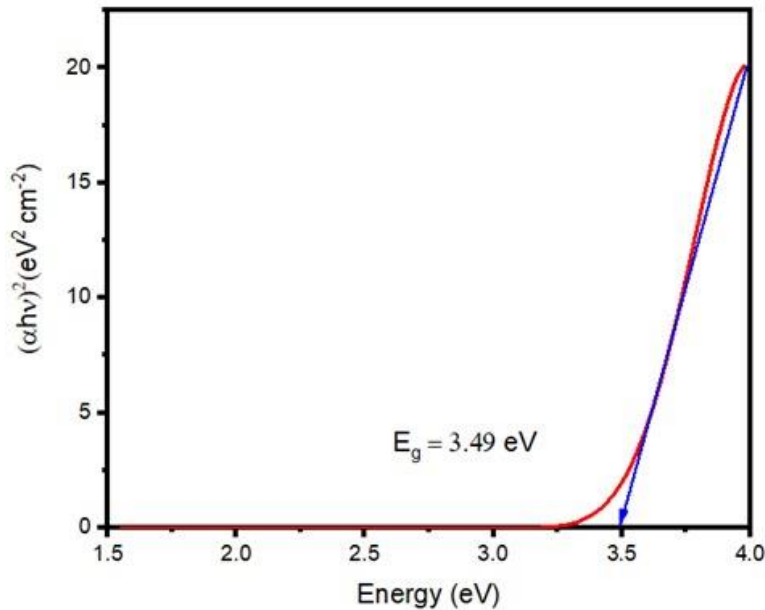


Fig. 6.7 optical band gap of undoped SnO₂ solution

6.3 ELECTRICAL PROPERTIES

6.3.1 HALL EFFECT

The sheet resistances of above prepared FTO thin films were studied using the van der pauw technique. We observed that as the low volume of current passed into the glass substrate, the sheet resistance was found to be high due to only a thin layer of FTO deposited. Our results showed the lowest sheet resistance of 1152 ohm/cm square for 1mA for 10% FTO film.

The electrical properties of films were characterized by hall effect technique. The results are reported in Table 2. Clearly, the resistivity decrease, with increasing current as shown in table. The resistivity of FTO films prepared by sol-gel is relatively high by comparison to their values in the ones prepared by other techniques. This discrepancy is mainly due to the low amount doping fluorine hosted in the SnO₂ network.

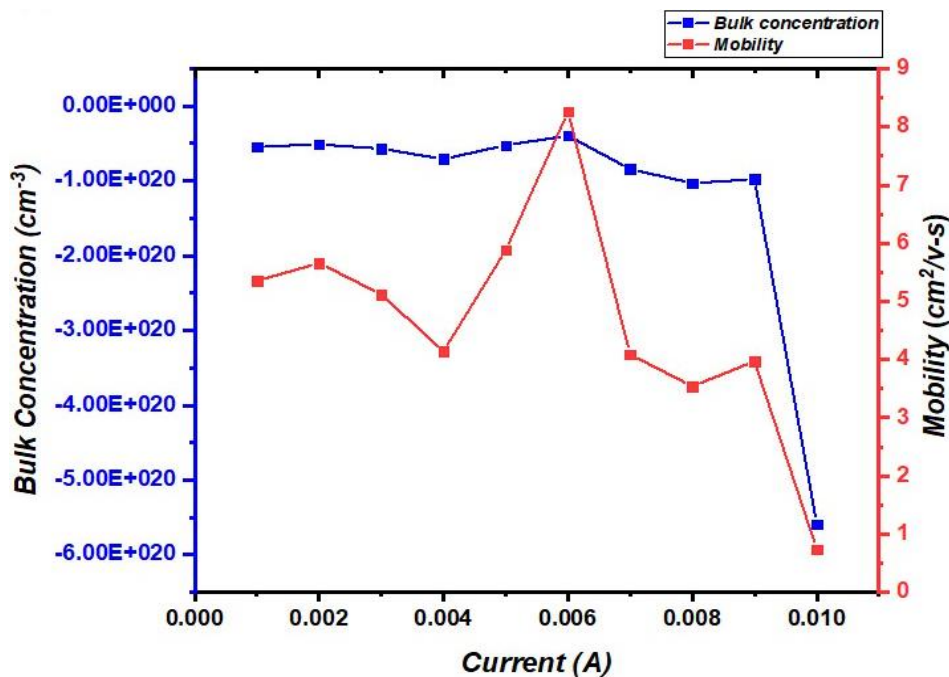


Fig. 6.8 shows the change of bulk concentration and Hall-mobility with respect to the change in current of the 10% SnO₂: F thin film.

The van der pauw is preferred for measurement of sheet resistance ($1152\text{ohm}/\text{cm}^2$); in the linear four-point probe technique, The Hall Effect measurements, which were recapitulated in Table 2, have been carried out to evaluate different electrical parameters such as resistivity, mobility and free carrier concentration. Also, the V/H ratio of the thin film was constant throughout the measurements.

Current[A]	Carrier Concentration (cm⁻³)	Resistivity (Ω. cm)	Mobility (cm² /V.s)
1.00×10^{-3}	-5.41×10^{19}	2.16×10^{-2}	5.35
2.00×10^{-3}	-5.12×10^{19}	2.15×10^{-2}	5.66
3.00×10^{-3}	-5.68×10^{19}	2.15×10^{-2}	5.12
4.00×10^{-3}	-7.07×10^{19}	2.13×10^{-2}	4.14
5.00×10^{-3}	-5.24×10^{19}	2.03×10^{-2}	5.88
6.00×10^{-3}	-3.94×10^{19}	1.92×10^{-2}	8.26
7.00×10^{-3}	-8.41×10^{19}	1.81×10^{-2}	4.09
8.00×10^{-3}	-1.03×10^{20}	1.71×10^{-2}	3.54
9.00×10^{-3}	-9.77×10^{19}	1.61×10^{-2}	3.97
10.00×10^{-3}	-5.59×10^{20}	1.52×10^{-2}	7.35×10^{-1}

Table 2. variation in carrier concentration, resistivity and hall- mobility of 10% fluorine doped tin oxide thin film

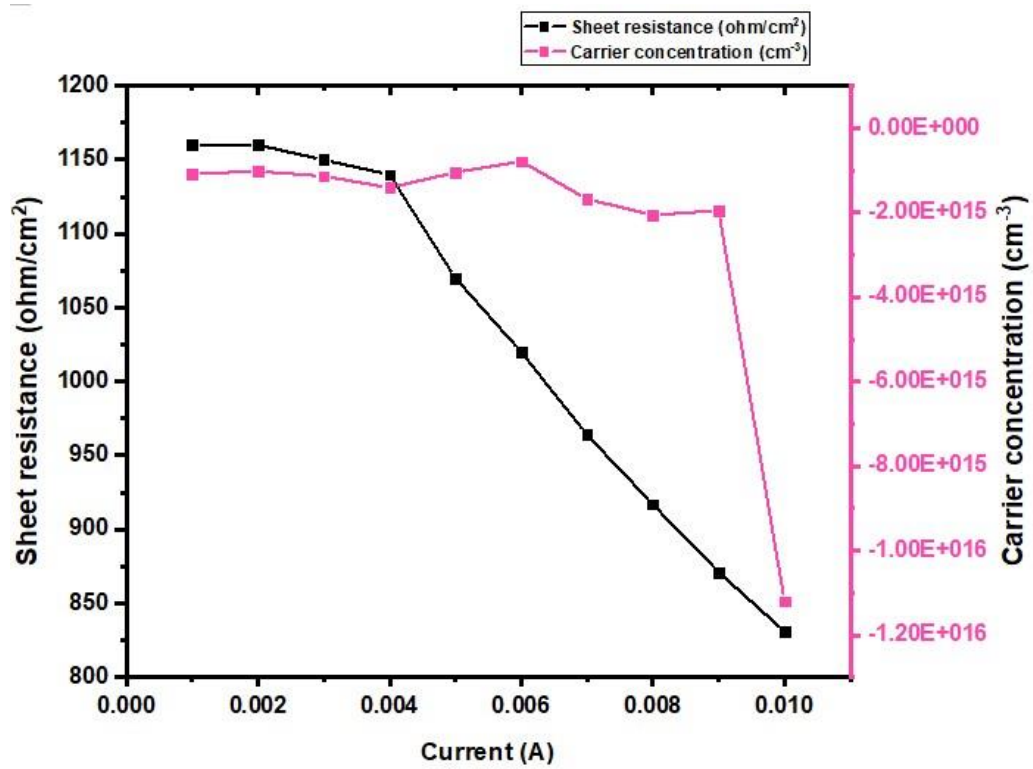


Fig. 6.9 shows the change of sheet resistance, carrier concentration and of the SnO₂: F thin film. SnO₂: F thin film resistance gradually decrease.

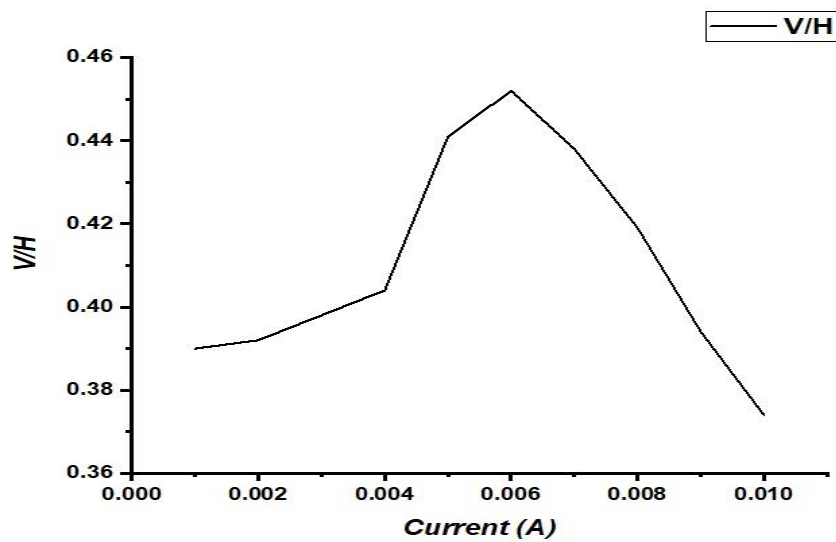


Fig. 6.10 shows the V/H ratio with respect to the current applied.

CHAPTER 7

CONCLUSION

In this work, 10% Fluorine doped tin oxide thin film is prepared on glass substrate by sol-gel spin coating method, and the structural, optical and electrical characteristics studied and compared with the results of pure tin oxide thin film prepared as part of another parallel study. The method of preparation was found to be economic and suitable for research and development.

The transmittance of 10% FTO film was found to be less than the pure SnO₂ film and the absorbance value is greater for fluorine doped tin oxide thin film. Where the transmittance of pure tin oxide film was found more than 90%.and the carrier concentration $7.0\text{E}+018\text{ cm}^{-3}$ and the mobility is $2.2\text{cm}^2/\text{s}$ for the undoped sample. The direct band gap was found to be of 3.33 eV for 10 % FTO film and 3.39-3.49 for solution and thin film samples of undoped tin oxide. The energy bandgap has decreased with an increased percentage of fluorine doping. The smaller the bandgap energy value possessed by the thin film, the easier it will be for electrons to move from the valence band to the conduction band. This results in the quality of a film being better used as a semiconductor material.

Hence, the film with 10% Fluorine concentration shows the best crystalline structure and has the high mobility, higher carrier concentration and lowest sheet resistance and lesser optical transparency, greater absorbance, smaller band gap energy shows that 10% Fluorine is the best concentration to improve the conductivity. Thus, fluorine doped tin oxide (FTO) could be a promisable application in the renewable energy and solar cell applications.

REFERENCES

A.R.Baber, S.S.Shinde, A.V.Moholkar, C.H.Bhosale, J.H.Kim and K.Y.Rajpure, J.Semicond. 32, (2011)5.

Aassime, A. and Hamouda, F., 2022. *Conventional and Un-Conventional Lithography for Fabricating Thin Film Functional Devices*.

Acosta, E., 2021. Chapter: Thin Films/properties and applications. *IntechOpen*. Available at: <https://www.intechopen.com/chapters/75002>

Adjimi, Amel, et al. "Fluorine-Doped Tin Oxide Thin Films Deposition by Sol-Gel Technique." *Journal of Crystallization Process and Technology*, vol. 08, no. 04, 2018, pp. 89–106., doi:10.4236/jcpt.2018.84006.

Akgul, F., Gumus, C., Er, A., Farha, A., Akgul, G., Ufuktepe, Y. and Liu, Z., 2013. Structural and electronic properties of SnO₂. *Journal of Alloys and Compounds*, 579, pp.50-56.

Anon, 2021. Solar inverter and its types. *Solar Power | Renewable Energy | Green Energy Blog*. Available at: <https://sunedisoninfra.com/blog/solar-inverterand-its-types/>

Anon, Thin films in Everyday Life. *Thin Films in everyday life - ALCA TECHNOLOGY S.r.l.* Available at: <https://www.alcatechnology.com/en/blog/thinfilms-in-everyday-life/>

Apex,et,al.,2011. "Spin Coating Systems." *Apex Instruments*, www.apexindia.com/products/spin-coating-unit.

Asm.com. 2022. *Atomic Layer Deposition*. [online] Available at: <<https://www.asm.com/technology/key-technologies/atomic-layer-deposition>>

AYDIN, Cihat, and Handan AYDIN. "The Synthesis and Optical Dispersions Parameters of Cadmium Doped Tin-Oxide Thin Films by the Sol-Gel Method."

Blyler, J., 2022. *Basics of Thin Film – How Thick is Thin?*. [online] designnews.com. Available at:
<<https://www.designnews.com/3dprinting/basics-thin-film-how-thick-thin>>

Boddolla, S. and Thodeti, S., 2018. A review on characterization techniques of nanomaterials. *International Journal of Engineering, Science and Mathematics*, 7(1), pp.169-175.

Britannica, The Editors of Encyclopaedia. "ethanol". Encyclopedia Britannica, 26 Aug. 2021, <https://www.britannica.com/science/ethanol>. Accessed 13 April 2022.

C. Agashe, J. Hupkes, G. Schope, and M. Berginski, *Solar Energy Materials & Solar cells*, 93, (2009), 1256-1262

C. Piras, C., Susana Fernández-Prieto & Borggraeve, W.M.D., 2019. Ball milling: A green technology for the preparation and functionalisation of nanocellulose derivatives. *Nanoscale Advances*. Available at:
<https://pubs.rsc.org/en/content/articlehtml/2019/na/c8na00238j>

Chapin DM, Fuller CS, Pearson GL. A new silicon p–n junction photo cell for converting solar radiation into electrical power. *Journal of Applied Physics* 1954; 25: 676.

Chi, L.; *Nanotechnology*, Volume 8: Nanostructured Surfaces, Weinheim, WILEY-VCH Verlag GmbH & Co. KGaA, 2010.

Choi, Y., Shin, S. H., Hong, S., & Kim, Y. (2016). A combined top-down/bottomup approach to structuring multi-sensing zones on a thin film and the application to SPR Sensors. *Nanotechnology*, 27(34), 345302.
<https://doi.org/10.1088/0957-4484/27/34/345302>

Chopra, K.L., Paulson, P.D. and Dutta, V., 2004. Thin-film solar cells: an overview. *Progress in Photovoltaics: Research and applications*, 12(2-3), pp.6992.

Cleaning Laboratory Glassware,
www.sigmaaldrich.com/US/en/technicaldocuments/protocol/chemistry-and-synthesis/reaction-design-andoptimization/cleaning-glassware.

Corrosionpedia. 2022. *What is a Physical Vapor Deposition (PVD)? - Definition from Corrosionpedia*. [online] Available at:
<<https://www.corrosionpedia.com/definition/875/physical-vapor-depositionpvd>>

Definitions.net. 2022. *What does thin film mean?*. [online] Available at:
<<https://www.definitions.net/definition/thin+film>>

Deposition, s., film, t., sulfide, C., sulfide, c., treatment, h., telluride, C., process, m., reaction, a., deposition, c., dioxide, T., process, d. and deposition, r., 2022.

Diaz Fernandez, Y.A. et al., 2014. The conquest of Middle-earth: Combining topdown and bottom-up nanofabrication for constructing nanoparticle based devices. *Nanoscale*, 6(24), pp.14605–14616.

Doyan, Aris, et al. "Synthesis of Tin Oxide Thin Layer by Doping Aluminum, Fluorine, and Indium Using Sol-Gel Spin Coating Technique." *Jurnal Penelitian Pendidikan IPA*, vol. 7, no. 1, 2020, pp. 11–14., doi:10.29303/jppipa.v7i1.468.

En.wikipedia.org. 2022. *Dry etching* - Wikipedia. [online] Available at: <https://en.wikipedia.org/wiki/Dry_etching>

Groups.ist.utl.pt. 2022. *Pulsed Laser Deposition*. [online] Available at: <http://groups.ist.utl.pt/rschwarz/rschwarzgroup_files/PLD_files/PLD.htm>

Gurvinder Singh Bumbrah, Rakesh Mohan Sharma, Raman spectroscopy – Basic principle, instrumentation and selected applications for the characterization of drugs of abuse, Egyptian Journal of Forensic Sciences, Volume 6, Issue 3, 2016, Pages 209-215, ISSN 2090-536X, <https://doi.org/10.1016/j.ejfs.2015.06.001>.
<https://www.sciencedirect.com/science/article/pii/S2090536X15000477>

Heavens, O.S. (2002). Optical Properties of Thin Films. Reports on Progress in Physics. 23. 1. 10.1088/0034-4885/23/1/301.

Isca.in. 2022. [online] Available at: <<http://www.isca.in/rjcs/Archives/v6/i7/10.ISCA-RJCS-2016-153.pdf>>

Journal of Physical Chemistry and Functional Materials, 2021, doi:10.54565/jphcfum.1019094.

Joyce, B., 1985. Molecular beam epitaxy. *Reports on Progress in Physics*, 48(12), pp.1637-1697.

Karmaoui, Mohamed, et al. "One-Step Synthesis, Structure, and Band Gap Properties of SnO₂ Nanoparticles Made by a Low Temperature Nonaqueous Sol–Gel Technique." *ACS Omega*, vol. 3, no. 10, 2018, pp. 13227–13238., doi:10.1021/acsomega.8b02122.

Katakam, P. et al., 2015. Top-down and bottom-up approaches in 3D printing technologies for drug delivery challenges. *Critical Reviews in Therapeutic Drug Carrier Systems*, 32(1), pp.61–87.

M. Anwar, I.M. Ghauri, and S.A. Siddiqi, Jour. Mater. Sci, 43, (2008), 6049-6056.
Maqsood, A., Islam, M., Ikram, M., Salam, S. and Ameer, S., 2012. Synthesis, Characterization and Hall Effect Measurements of Nanocrystalline ZnO Thin Films. *Key Engineering Materials*, 510-511, pp.186-193.

Martinot E, Chaurey A, Lew D, Moreira JR, Wamukonya N. Annual Review of Energy and Environment. 2002; 7: 309– 348.

Maycock PD. Top PV cell/module producers. Photovoltaic News 2003; 22(2): 2.

Muliyadi, Lalu, et al. "Synthesis of SnO₂ Thin Layer with a Doping Fluorine by Sol-Gel Spin Coating Method." *Jurnal Penelitian Pendidikan IPA*, vol. 5, no. 2, 2019, pp. 175–178., doi:10.29303/jppipa.v5i2.257.

Muliyadi, Lalu, et al. "Synthesis of SnO₂ Thin Layer with a Doping Fluorine by Sol-Gel Spin Coating Method." *Jurnal Penelitian Pendidikan IPA*, vol. 5, no. 2, 2019, pp. 175–178., doi:10.29303/jppipa.v5i2.257.

Naghdi, Samira. (2021). Thin films- definition, deposition techniques, and applications. 10.13140/RG.2.2.35029.96480/1.

Ossila. 2022. *Spin Coating: Complete Guide to Theory and Techniques*. [online] Available at: <<https://www.ossila.com/pages/spin-coating>>

Potassium Dichromate. *National Center for Biotechnology Information. PubChem Compound Database*, U.S. National Library of Medicine, pubchem.ncbi.nlm.nih.gov/compound/Potassium-dichromate.

Precision Micro. 2022. *Chemical Etching | What is Chemical Etching & How Does it Work?*. [online] Available at: <<https://www.precisionmicro.com/chemicaletching/>>

Prince M. 50th Anniversary of Bell Labs solar cell discovery. Proceedings of the 3rd World Conference and Exhibition on Photovoltaic Solar Energy Conversion, 2003; in press.

Rameshkumar, C., Ananth, D., Divyalakshmi, V., Balakrishnan, M., Senthilkumar, G. and Subalakshmi, R., 2021. An investigation of SnO₂ nanofilm for solar cell application by spin coating technique. *MATERIALS, MECHANICS & MODELING (NCMMM-2020)*.

Rameshkumar, C., et al. "An Investigation of SnO₂ Nanofilm for Solar Cell Application by Spin Coating Technique." *Materials Today: Proceedings*, vol. 45, 2021, pp. 6042–6045., doi:10.1016/j.matpr.2020.09.732.

Rogers, J.A.; Lee, H.H.; *Unconventional Nanopatterning Techniques and Applications*, Hoboken, New Jersey, John Wiley & Sons, 2009.

Roguai, Sabrina, and Abdelkader Djelloul. "Synthesis and Investigation of Structural, Microstructural and Optical Properties of Iron-Doped SnO₂ Nanoparticles : Application in Photocatalysis." 2021, doi:10.21203/rs.3.rs513448/v1.

Saleh, S. & Ibrahim, Ahmed & Mohamed, S.H.. (2016). Structural and Optical Properties of Nanostructured Fe-Doped SnO₂. *Acta Physica Polonica A*. 129. 1220-1225. 10.12693/APhysPolA.129.1220.
Solar Cells, 93, (2009), 1256-1262

Soumya, S. S., et al. "Conductivity Type Inversion and Optical Properties of

Aluminium Doped SNO₂ Thin Films Prepared by Sol-Gel Spin Coating Technique.” *Journal of Sol-Gel Science and Technology*, vol. 99, no. 3, 2021, pp. 636–649., doi:10.1007/s10971-021-05599-7.

Spin Coating: Complete Guide to Theory and Techniques. Ossila, www.ossila.com/pages/spin-coating.

Staff.ustc.edu.cn. 2022. [online] Available at: <<http://staff.ustc.edu.cn/~fuzp/course/paper/Thin%20film%20deposition%20using%20spray%20pyrolysis.pdf>>

Susilawati, et al. “The Thickness Effect to Optical Properties of SNO₂ Thin Film with Doping Fluorine: Semantic Scholar.” *Undefined*, 1 Jan. 1970, [www.semanticscholar.org/paper/The-thickness-effect-to-optical-properties-of-SnO₂-Susilawati-Doyan/55c771f45784e08fc3f39db3dade3c88a6edeb37](http://www.semanticscholar.org/paper/The-thickness-effect-to-optical-properties-of-SnO2-Susilawati-Doyan/55c771f45784e08fc3f39db3dade3c88a6edeb37).

Text-id.123dok.com. 2022. *Advantages and disadvantages of spin coating thin film*. [online] Available at: <<https://text-id.123dok.com/document/myjo61l2zadvantages-and-disadvantages-of-spin-coating-thin-film.html>>

Tomastik, Jan & Ctvrtlik, Radim & Šebestová, Hana & Schovanek, P. & Jankuj, Jiri & Hrabovsky, M.. (2012). Mechanical properties of optical thin films. *Proceedings of the 50th Annual Conference on Experimental Stress Analysis*. 469-476.

US8409407B2 - *Methods for high-rate sputtering of a compound semiconductor on large area substrates* - Google Patents. [online] Patents.google.com. Available at: <<https://patents.google.com/patent/US8409407B2/en>>

Vedantu. “Stannous Chloride.” *VEDANTU*, Vedantu, 24 June 2020, www.vedantu.com/chemistry/stannous-chloride.

Verma, G. and Mishra, M., 2018. Development and optimization of UV-Vis spectroscopy—A review. *World Journal of Pharmaceutical Research*, 7(11), pp.1170-1180.

Wang, Y., Wei, C., Cong, H., Yang, Q., Wu, Y., Su, B., Zhao, Y., Wang, J., & Jiang, L. (2016). Hybrid top-down/bottom-up strategy using superwettability for the fabrication of patterned colloidal assembly. *ACS Applied Materials & Interfaces*, 8(7), 4985–4993. <https://doi.org/10.1021/acsami.5b11945>

Zhang, X & Stroud, David. (1995). Optical and electrical properties of thin films. *Physical review. B, Condensed matter*. 52. 2131-2137. 10.1103/PhysRevB.52.2131.