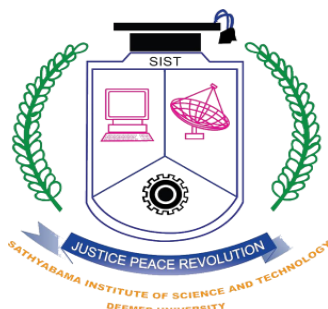


ALUMINIUM (Al) DOPED ZINC OXIDE (ZnO) THIN FILM FOR LONG HAUL COMMUNICATION DEVICES

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

By

D. SANTHOSH
(41590017)



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 D. SANTHOSH (41590017) who carried out the project entitled "ALUMINIUM (Al) DOPED ZINC OXIDE (ZnO) THIN FILM FOR LONG HAUL COMMUNICATION DEVICES" under my supervision from November 2022 to May 2023.

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Head of the Department
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Submitted for Viva voce Examination held on 9.5.2023 2023

INTERNAL EXAMINER

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DECLARATION

I D. SANTHOSH hereby declare that the Project Report entitled ALUMINIUM (Al) DOPED ZINC OXIDE (ZnO) THIN FILM FOR LONG HAUL COMMUNICATION DEVICES 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

In this brief report, Aluminium-doped zinc oxide (AZO) has emerged as a promising material for various technological applications due to its unique properties and versatile synthesis methods. We present a comprehensive overview of AZO, including its synthesis, properties, and applications.

We discuss the different synthesis methods of AZO, including sol-gel, chemical vapour deposition (CVD), and physical vapour deposition (PVD), along with their advantages and limitations. We highlight the effect of aluminium doping concentration on the structural, electrical, and optical properties of AZO, including its high electrical conductivity, excellent transparency in the visible region, and optical properties.

Finally, this review provides a comprehensive understanding of aluminium doped zinc oxide, its synthesis, properties, and applications, and serves as a valuable resource for researchers, scientists, and engineers working in the field of materials science and engineering.

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LIST OF ABBREVIATIONS

CVD	Chemical vapor Deposition
PVD	Physical vapor Deposition
ALD	Atomic layer Deposition
PLD	Pulsed laser Deposition
MBE	Molecular Laser Epitaxy
CE	Chemical Etching
RPM	Rotation Per Minute
XRD	X-Ray diffraction
UV-VIS SPECTROSCOPY	Ultra violet Visible spectroscopy

CHAPTER-1

1.1 Introduction:

Thin film refers to a layer or coating of material that is typically very thin, often in the nanometer (nm) to micrometer (μm) range. Thin films are used in a wide range of applications, including electronics, optics, solar cells, displays, sensors, and coatings. They are characterized by their unique properties and behavior at the Nano scale, which can differ significantly from those of bulk materials.

Thin films can be deposited onto various substrates, such as glass, silicon, metals, or polymers, using different techniques, including physical vapor deposition (PVD), chemical vapor deposition (CVD), sputtering, and evaporation. These techniques allow precise control over the film's thickness, composition, and microstructure, which in turn can tailor the film's properties for specific applications.

Thin films exhibit various intriguing properties that make them highly desirable for many technological applications. For example, thin films can have enhanced mechanical, electrical, optical, and magnetic properties compared to their bulk counterparts, due to quantum confinement effects and increased surface-to-volume ratio. Thin films also offer the advantage of being flexible, lightweight, and adaptable, making them suitable for a wide range of devices and systems.

Thin film technology has found widespread use in many industries, including semiconductor manufacturing, optical coatings, aerospace, automotive, energy, and healthcare. Thin films are crucial in the production of integrated circuits (ICs), displays, solar cells, and sensors. They are also used in anti-reflective coatings for optical lenses, corrosion-resistant coatings, and drug delivery systems in medicine, among many other applications.

Research and development in thin film science and technology continue to advance, leading to new and exciting applications and discoveries. The unique properties and versatility of thin films make them a fascinating field of study with broad-ranging practical implications.

1.2 Definition:

A thin film is a thin layer of material with a thickness ranging from a fraction of a Nano meter to several micrometers. The principal applications that profit from thin- film fabrication are electronic semiconductor devices and optical coatings. The household mirror, which typically includes a thin metal coating on the back of a sheet of glass to generate a reflecting surface, is a well-known application of thin films. Silvering was previously a typical method for producing mirrors. Two-way mirrors are made using a very thin film covering. When a thin-film coating consists of numerous layers of varied thicknesses and refractive indices, optical coating performance is often improved (Definitions.net. 2022).

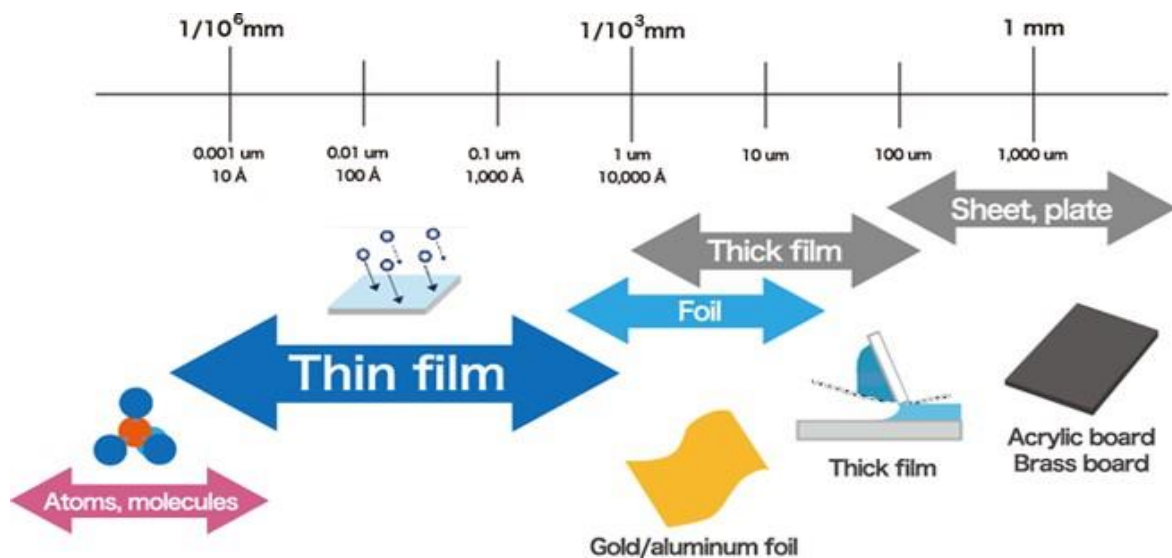


Fig 1.1 Thin film technology

Batteries, electronics (typically printed) such as diodes, transistors, and memory. and thin film photovoltaic (PV) solar cells are just a few of the uses for thin-film foil textiles in the electronics field. Thin-film electronics is also finding a rising demand in medical and wearable applications.

Thin film semiconductor electronics have grown in popularity in recent years as a result of its advantages over traditional silicon devices, such as improved efficiency. Smaller weight, reduced space consumption, and shape flexibility.

Thin films can be made in a variety of methods. A mirror, for example, is made composed of a sheet of glass with a thin metal coating placed to the reflective surface. Sputtering, the modern method for making a mirror, is part of a larger category of processing processes known as deposition. Magnetic recording media, semiconductor devices, optical coatings (such as mirrors and antireflective coating), hard coatings on cutting instruments and energy generation are all examples of thin films deposition applications (eg. Thin-film solar cells).

1.3 Importance of Thin film

Thin films have become such an integral part of human existence that it is difficult to imagine a field of activity without them. The first thin films were used for optical purposes in 1912. Paul and Pringsheim have published remarkable work on the fabrication of mirrors using his high-vacuum evaporation technique of metals such as Ag and Al from MgO crucibles. Since then, thin film coatings have been used in a variety of optical applications, including antireflective coatings, scratch resistant coatings, and UV and IR reflective coatings. At the same time, decorative coatings, tribological coatings, biomedical coatings, self-cleaning coatings, and other engineering fields began to benefit from this technology. One of the areas where thin films are not as it were valuable, but too they constitute the key fabricating innovation, is the industry of semiconductors, which incorporates: broadcast communications gadgets, coordinates circuits, transistors, sun based cells, LEDs, photoconductors, LCDs, magneto-optic recollections, compact plates, electro-optic coatings, recollections, flat-panel shows, smart windows, computer chips, magneto- optic drives, micro electro mechanical frameworks, and multifunctional coatings.

1.3.1 Thin Film in Optical Coating

Optical coatings involve applying one or more layers of metal or ceramic fabrics onto an optical fabric such as a glass or plastic focus to modify its transmission and reflection properties. The use of anti-reflection coatings is for optical coatings that reduce reflections from optical surfaces B. It reduces the focus of the photo. This effect can be achieved without significantly changing device yield. This is because the substrate fabric low.

1.3.2 Thin film in preventing corrosion and wearing

In addition to protecting against wear, the thin film helps prevent corrosion of the steel parts of many devices. Fabrics, jewelry, watches and knives are regularly covered to prevent corrosion. Thin film coatings are also used as tarnish protection for some sensitive materials such as silver in ring packaging. Metals such as chromium and zinc are typically used in plating to prevent corrosion, but some exceptional hard ceramic substances such as titanium nitrate, chromium nitrate and aluminum oxide are used to prevent devices and equipment from sporting.

1.3.3 Thin film in semi-conductor

Integrated circuits, as well as various semiconductor devices, are units consisting of stacks of semiconducting semiconductors and thin films of insulating material. Thin films are deposited on perfectly flat substrates, often creating closed circuits composed of chemical elements or carbides. A carefully designed stack of thin layers is then deposited onto this substrate, also called a "wafer." Each layer is carefully floral zed using lithographic printing techniques, contemplating the simultaneous fabrication of a vast range of power and passive devices. Since the tools are made from interconnections of otherwise doped thin-film layers, interconnections between different devices are managed using thin-film metal layers, commonly made of Al or copper. This generation enabled the miniaturization of many basic semiconductor devices such as BJTS, FETS, MOSFETS and diodes, resulting in the manufacture of sophisticated computers, memory and integrated circuits with overall high performance is now possible.

1.3.4 Thin film in Opto - electronics

One another subject on which the thin film era has emerged as a basis is optoelectronics. Using techniques similar to those used in integrated circuit fabrication (deposition/lithography), it is feasible to fabricate some of the most important devices that exist today. LED and OLED gadgets for lighting and display applications, LCDs, CMOS sensors for video cameras, and more. Surprisingly, thin film technology also allows the deposition of demonstrably conductive layers.

For example, indium tin oxide (ITO) coatings are commonly used in the form of visible and visible conductive electrodes. Thin-film manufacturing

was also used to make thin-film batteries, which were then incorporated into chips.

1.3.5 Thin film in protective and Decorative coating

Thin films are used to protect many artifacts, especially the bottom of optics, from debris, scratches, fingerprints, or corrosion. There are also secondary options for protective thin film coatings such as affects decorative effect, surface gloss, visible color and texture. Someday, thin films will be used only for decorative purposes. For deformed metal coatings on plastic substrates, they can be made using AN evaporation technology under high vacuum.

1.3.6 Thin film in solar cell

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.

1.3.7 Thin film in Nanotechnology

In nanotechnology is one of the maximum current advances in the take a look at of thin films. This involves coating with Nano composite materials thereby giving the substances progressed mechanical residences

because of a so-referred to as "length impact". The very last purposeful outcomes which can be obtained are: oxidation resistance, excessive adherence, low thermal conductivity, put on- resistance, higher longevity, and hardness. Due to the excessive purity and coffee stage of defects which are allowed by means of this technique. In conclusion, the function thin films play in our daily lives is limitless as many greater inventions are being made in the have a look at of thin films. Thin film era has been used to this point from the textile or fabric enterprise, to the gadgets, utensils, decoration and many others all of which are products very beneficial in our normal life. Thin film technology has performed an important position in making lifestyles simpler for all of us.

1.3.8 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.

1.4 History

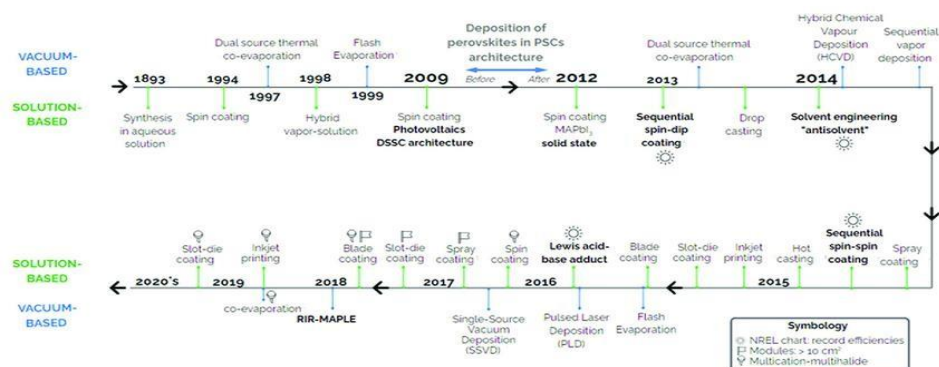


Fig 1.2 History and Development of thin film

In the following a brief history of thin technology is given for the sake of completeness.

1650 - Observation and interpretation of interference patterns (Eg. oil and water) by R. Boyle, R. Hooke, I. Newton.

1850 - Development of first deposition techniques (M. Faradays: W Grove; TA Edison) and of methods of thickness determination (Arago. Fizcas: Wernicke: Wiener) Commercial introduction of electrochemistry (Galvani's) for gold plating of Uniform-accessories.

1940: Industrial manufacturing of coating for optical, electronically and mechanical application (mostly military).

1965: thin film technology develops to an integral part of the mass manufacturing process in semiconductor and optical industry.

1990: thin films of High Tc-Superconductors.

1995: Thin film processing allows for the tailoring of microstructures of atomic and microscopic dimensions (Quantum-Dots by PVD, Cu-technology" by electrochemistry applied to integrated circuits).

2000: Manufacturing of Nano crystalline materials with defined composition and structure, For applications as protective coatings and in tribology. Deposition of highly ordered two, three dimensional objects with sizes in the nm range.

2004: Up scaling of complex reactive coating processes for industrial applications (coatings on glass, thermal management) Combinational investigation of ternary and quaternary material systems.

2006: investigations of organic coatings lead to the emergence of organic electronics (OLED, printable circuits).

1.5 Properties

1.5.1 Optical properties

Examining semi-conductor properties is made easy with optical experiments. The band gaps of the material are specifically revealed by measuring the absorption coefficient for various energies. Understanding these band gaps is crucial for comprehending a

semiconductor's electrical characteristics, and as a result, it is of tremendous practical relevance. (Verma, A., et al., 2007)

1.5.2 Mechanical properties

Mechanical properties of thin films often differ from those of the bulk materials. This can be partially explained by the nanostructure of thin films and the fact that these films are attached to a substrate. Due to typically 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, or interfacial delamination. Both elastic and plastic properties are important for thin film characterization. Thin film mechanical properties can be measured by tensile testing of freestanding films and by the micro beam cantilever deflection technique, but the easiest way is by means of Nano indentation, since no special sample preparation is required and tests can be performed quickly and inexpensively.

1.5.3 Electrical properties

The two semi-conductors and the dielectric are two of the three categories of electron materials. It is impossible to define all sorts of materials' electrical transport networks because they are obviously distinct. However, scaling effects start to have a similar impact on the electrical characteristics of materials in this film form. The kind, mechanism, and stability of the electrical transport are defined by the film thickness, the lattice parameters, the purity, the surface roughness, and the layer's imperfection level.

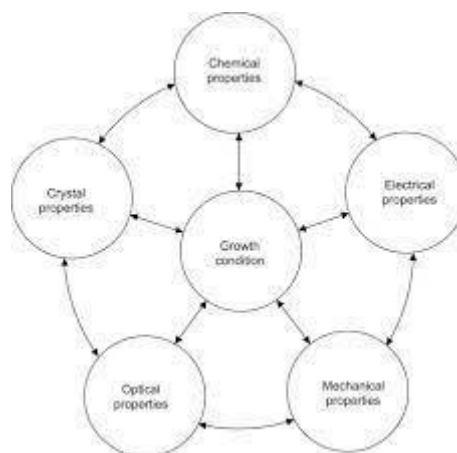


Fig 1.3 Properties of thin film

1.6 Application

They were employed in electronics to create flexible polymer light-emitting displays. For umbrella glass, they are employed in optical coating and anti-reflex coatings. Used to create SQUIDS films, which are super conducting films. They are useful in producing extremely effective magnetic films that can be used for reading and storing data. They go towards the creation of window coating. Thin films are utilized to coat turbine blades to prepare energy because of their excellent heat and corrosion resistance. They are utilized to create extremely hard coatings because of their tremendous mechanical properties. They are utilized in both protective and ornamental coatings. They are used to create photovoltaic cells, which are solar cells, due to their strong optical conductivity. These materials have already been applied to integrated circuits, wireless communications, semiconductor devices, and telecommunications.



Fig 1.4 Applications of thin film

1.7 Deposition Technique

The stability and morphology of thin films are the key factors in all applications. The deposition techniques have a significant impact on the thin film's morphology. A crucial stage in numerous applications is the carefully regulated production of materials as thin films. The physical and chemical depositions of thin films are also options.

1.7.1 Physical deposition technique

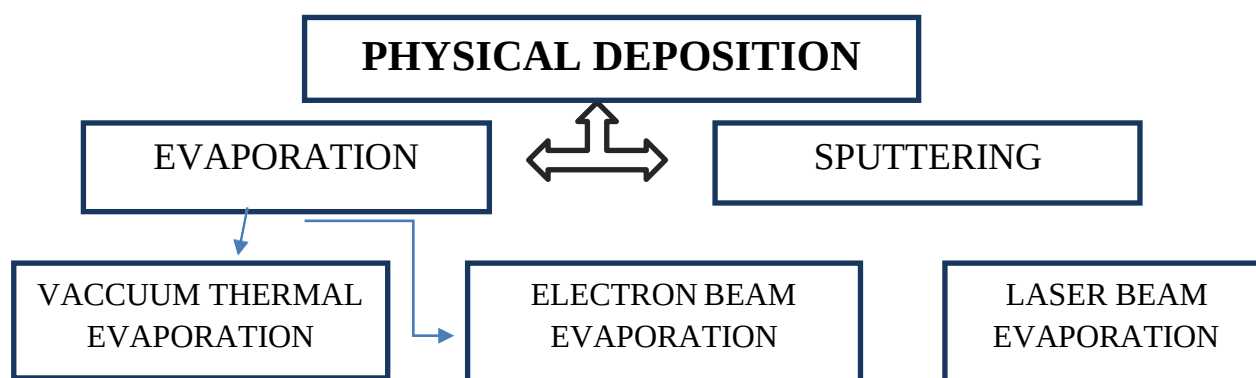


Fig 1.5 Physical deposition technique

1.7.2 Top down

(i) Ball Milling

A mechanical method for combining ingredients and finely powdering powders is ball milling. Because it is a practical and economical strategy, it has a wide range of applications in industry around the world. The numerous industrial machine types will not be covered in this mini-review because the emphasis is on the circumstances employed to prepare and functionalize Nano cellulose derivatives in a ball mill rather than the equipment. Depending on their intended application, ball mills come in many forms. The typical design, however, consists of a hollow cylindrical shell that spins around its axis and is partially filled with steel, stainless steel, ceramic or rubber balls. (Pira's C et al., 2019).

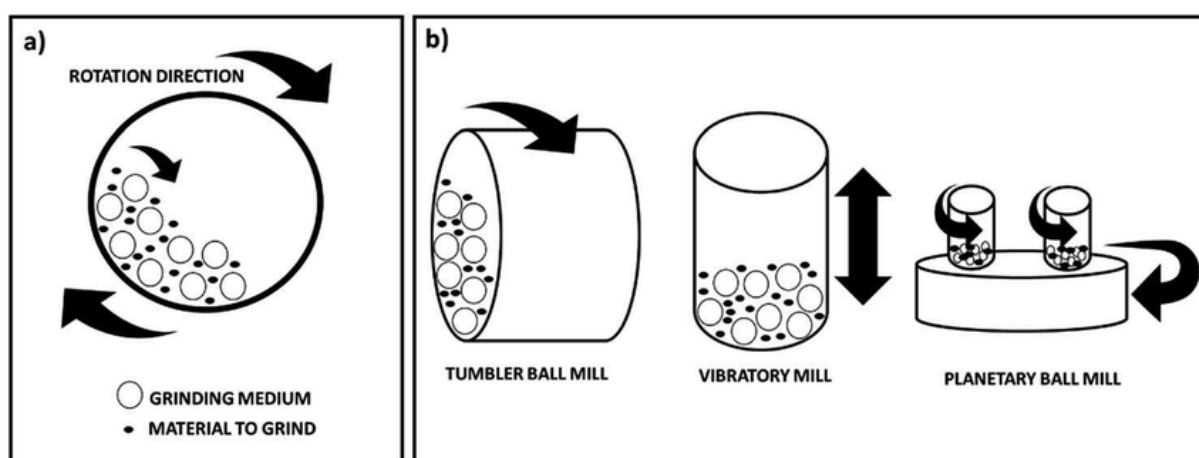


Fig 1.6 Schematic representation of a ball Mill (Horizontal section)

(ii) Dry Etching

By bombarding it with Ions (typically plasma of reactive gases like fluorocarbons, oxygen, chlorine, and boron trichloride; occasionally with the addition of nitrogen, argon, and other gases) that dislodge some of the material from the exposed surface, dry etching is a process for removing material typically a masked pattern of semiconductor material. A common type of dry etching is reactive-ion etching. The dry etching procedure frequently etches in a directed or anisotropic way, in contrast to many (but not all) of the wet chemical etchants employed in wet etching (En.wikipedia.org. 2022).

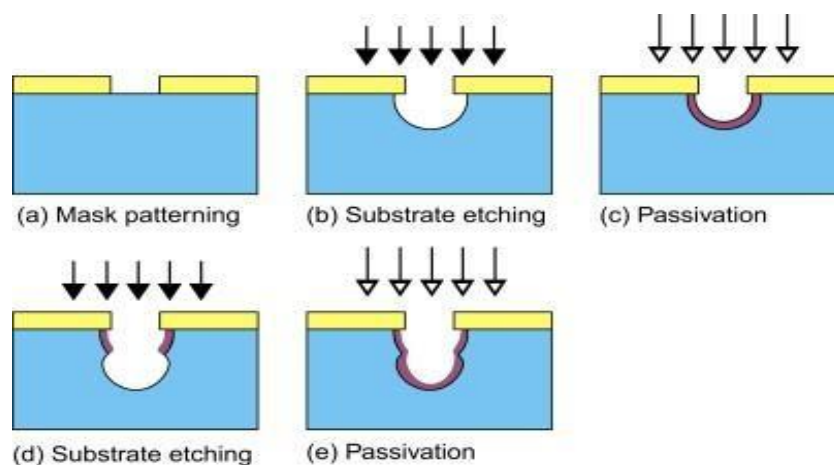


Fig 1.7 Dry etching

(iii) Lithography

Smaller, higher performing systems are still on the rise, which has encouraged new research and development into novel materials and devices with improved and unique characteristics. The extreme sensitivity of current submicron technologies opens up opportunities for thin film functional devices, such as magnetic thin film structures for data processing technology, sensing devices for biomedical applications, and capacitors for power components. Most of these devices were created in a top-down perspective using a combination of lithography, etching, and deposition processes. This chapter will demonstrate how conventional and non-conventional lithography can be utilized in conjunction with the PVD method to produce thin film functional devices.

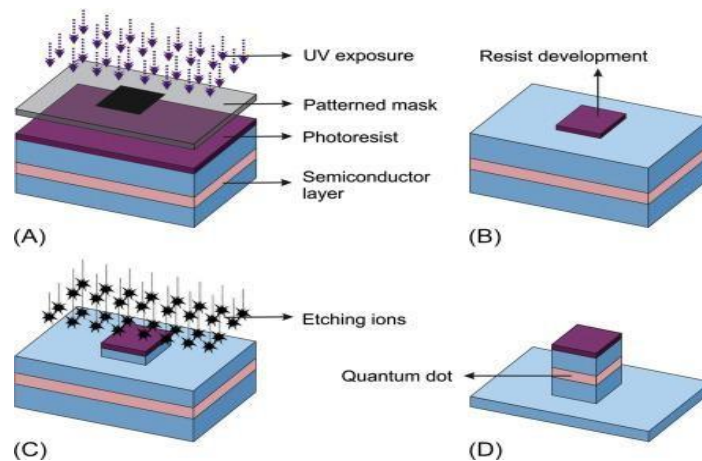


Fig 1.8 Lithography

1.7.3 Bottom up

1) Chemical Vapour Deposition

Chemical Vapour Deposition may be an activity during which the gaseous precursors are used. Precursor gases are affected into a chamber with the substrate. The chemical process between the substrate and also the precursor is sustained at extreme temperature until the required thickness of the film obtained (Wikipedia).

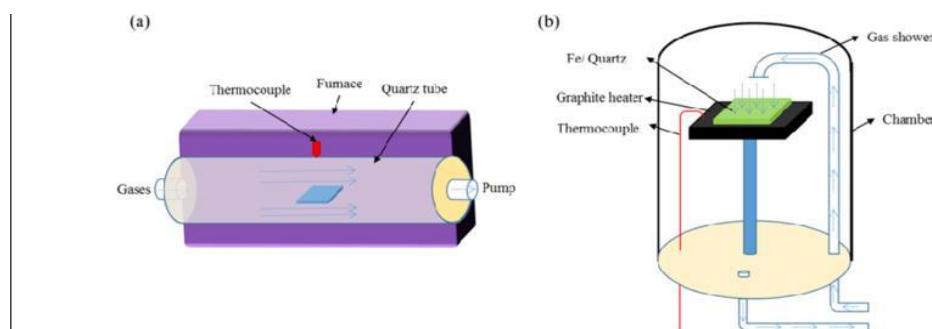


Fig 1.9 Schematic diagram of CVD

2) Physical Vapour Deposition:

The high-purity solid coating material (metals such as titanium, chromium, and aluminium) is either evaporated by heat or bombarded with ions in the physical vapour deposition process (sputtering). At the same time, a reactive gas (such as nitrogen or a carbon-containing gas) is injected; it reacts with the metal vapour and creates a thin, highly adherent coating on the substrate. As a result, the film has a very strong bond with the tooling substrate, as well as

customized physical, structural, and tribological properties (Corrosionpedia 2022).

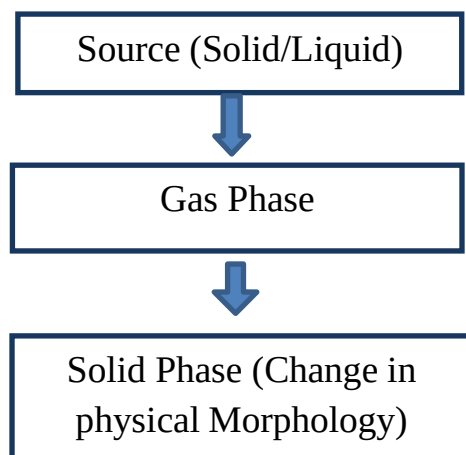


Fig 1.10 Physical vapor deposition

3) Atomic Layer Deposition

Deposition of Atomic Layers One atomic layer of a thin film is created by the surface-controlled layer-by-layer deposition technique known as (ALD). Precursors and reactants are pulsed alternately throughout reaction cycles, with an inert gas purge occurring between each pulse to generate layers (Asm.com. 2022).

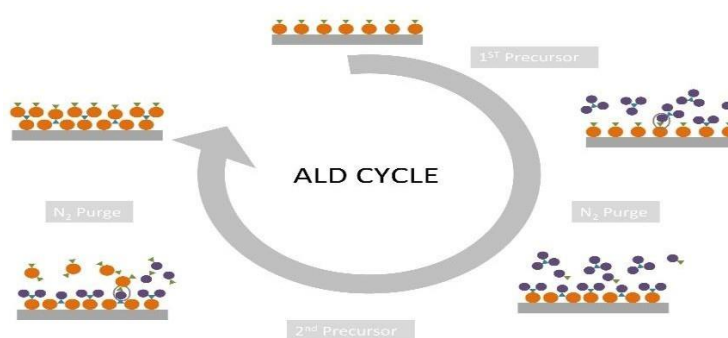


Fig 1.11 Atomic Layer Depositions

4) Pulsar Laser Deposition

Pulsed-laser deposition (PLD) has received a lot of attention lately since it is simple to use and effective at depositing materials with complicated stoichiometry. The first successful deposition of a superconducting YBa₂Cu₃O₇ thin film was accomplished by PLD. Since then, PLD has

successfully deposited a range of materials, including multi-element oxides, which are frequently challenging to deposit using conventional techniques (Groups.ist.utl.pt. 2022).

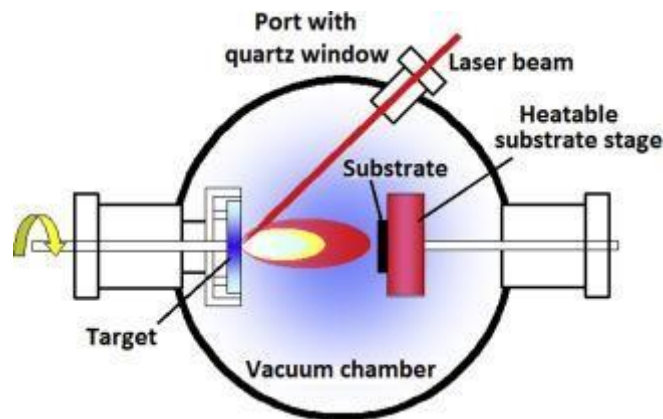


Fig 1.12 Pulsar Laser Deposition

5) Molecular Bean Epitaxy

Molecular Bean Epitaxy combines the advantages of chemical and physical thin film deposition methods. First, heat is applied directly to the target materials to be deposited until they change state from solid to gaseous. The thin film is then formed by allowing the gaseous components to react chemically with the substrate. Target material is deposited in the form of layers in Molecular Bean Epitaxy; however, each layer is added one at a time. Despite the fact that MBE is a laborious process, it achieves an extremely high degree of purity (Joyce B et al., 1985).

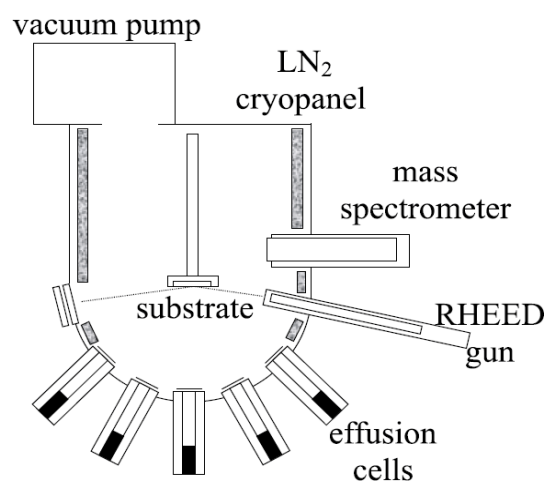


Fig 1.13 Molecular Bean Epitaxy

1.7.2 Chemical Deposition technique

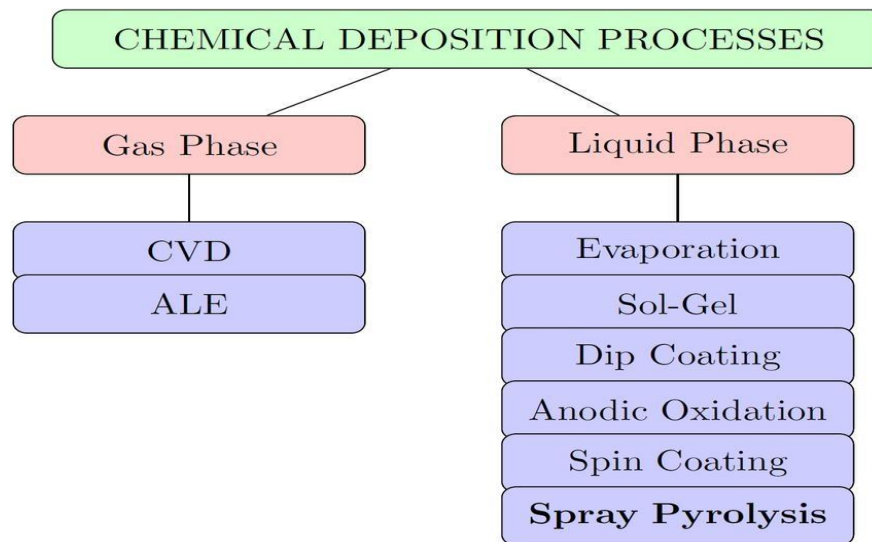


Fig 1.14 Chemical deposition technique

1.7.2.1 Top Down

1) Chemical Etching

Chemical etching, commonly referred to as chemical milling or photo etching, is a subtractive sheet metal machining technique that produces intricate and extremely precise precision components from virtually any metal (Precision Micro. 2022).

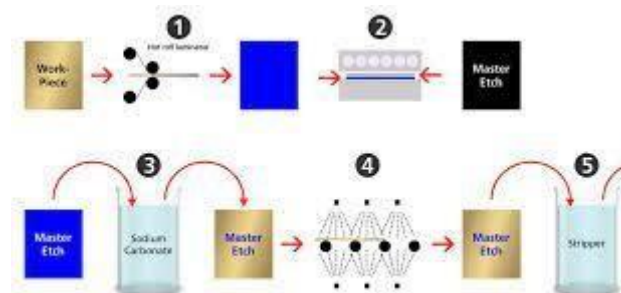


Fig 1.15 Chemical Etching

1.7.2.2 Bottom up

The sol-gel method combines a number of techniques for creating materials from solutions, with one of the processing phases being gel formation. The most popular technique for creating sol-gel is

controlled chemical hydrolysis usually with alkoxides. In an organic or aqueous media, M (or) X ($M=Ti, Si, V, Zr, Mo, Al, Sn$, etc..) or the equivalent chlorides.

2) Dip coating

A dip coating material is applied to a moving web of flexible substrate during the coating process. The carrier substrate can be paper, film or aluminum foil, and the additional qualities of the produced material will differ based on the needed application and the intended usage of the material.

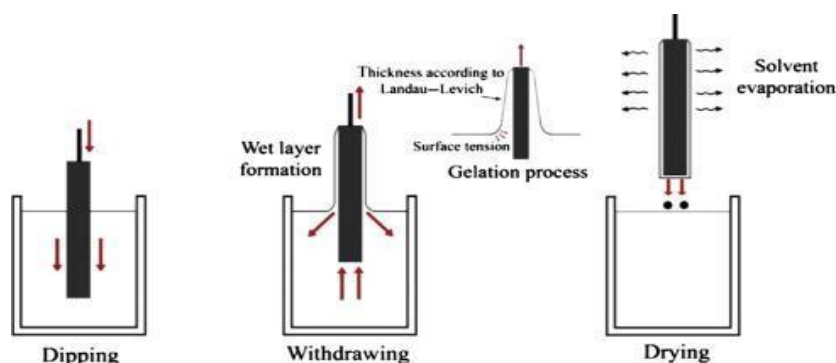


Fig 1.16 Dip coating deposition

3) Spin Coating

A typical spin process consists of a dispense step in which the resin fluid is deposited onto the substrate surface, a high-speed spin step to thin the fluid, and a drying step to eliminate excess solvents from the resulting film. Two common methods of dispense are Static dispense, and Dynamic dispense.



Fig 1.17 Spin coating

4) Spray pyrolysis

In spray technique, spray solution is spread on hot substrate and other volatile by products and excess solvent are removed in the form of vapours. Spraying technique apparatus involves spray nozzle, motor, liquid level monitors, hot plate, Gas regulator valve and air tight fibre chamber (Staff.ustc.edu.cn. 2022)

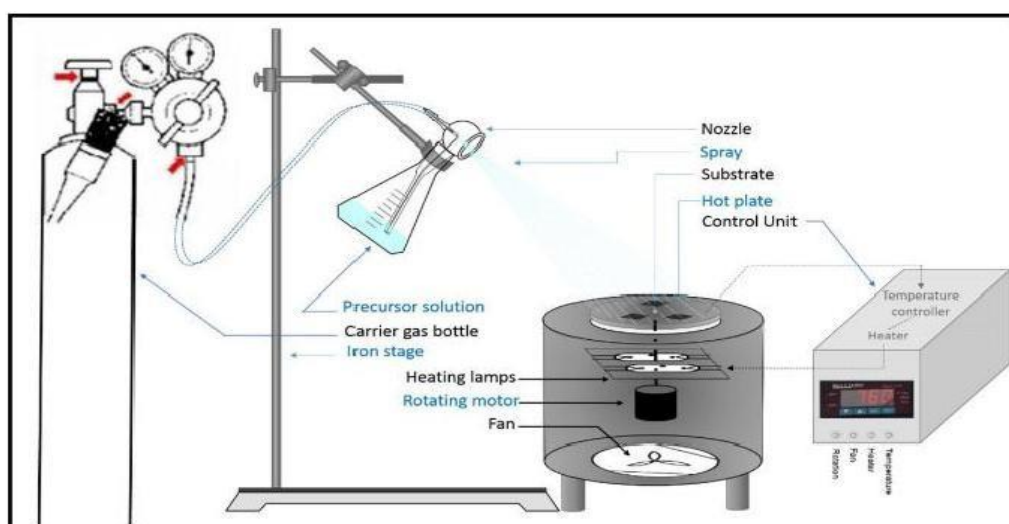


Fig 1.18 Spray pyrolysis

UNIT-2

LITERATURE SURVEY

1 . Morphological, Structural and Optical Properties of ZnO Thin Films Deposited by Dip Coating Method Sara Maroufa, Abdelkrim Beniaichea, Hocine Guessasa, Amor Azizib *

The effects of sol aging time on the deposition of ZnO films were studied using FE-SEM, AFM, X-ray diffraction, and optical transmission techniques. Increased sol aging time resulted in improved crystallinity and increased optical transparency. 72-168 h sol aging time was found to be optimal for smooth surface morphology, good crystallinity, and high optical transmittance.

2. Aluminum doped ZnO transparent conducting thin films prepared by sol-gel dip coating technique for solar cells and optoelectronic applications.

V. Balaprakash, P. Gowrisankar, S. Sudha , R. Rajkumar

Aluminium-doped ZnO nanostructured transparent conducting thin films were deposited on a glass substrate and investigated for structural, morphological, electrical and optical properties. Results showed high intensity razor-sharp peak, porous nanostructure, electrical resistivity of $3.2 \times 10^{-2} \text{ cm}$, over 90% transmittance, and optical band gap energies of 3.34 eV to 3.62 eV.

3. Synthesis and electrical characterization of Aluminium doped zinc oxide thin film. M. VANMATHI^{a*}, I. MOHAMED^a, S. K. MARIKKANNAN^b, M. VENKATESWARLU^c

Al doped ZnO (AZO) thin films were deposited using solgel technique and studied for structural, optical and electrical properties. XRD studies showed that AZO thin films had a preferred orientation and decreased lattice distance, indicating a less defected structure. The electrical and optical properties of AZO films reached a good level, with electrical resistivity as low as $1.84 \times 10^3 \text{ cm}$ and 90% optical transmittance in the visible region.

4. Optical properties and electrical resistivity of boron-doped ZnO thin films grown by sol-gel dip-coating method

Author [links](#) [open](#) [overlay](#) [panel](#) Soaram Kim ^a, Hyunsik Yoon ^a, Do Yeob Kim ^b, Sung-O Kim ^b, Jae-Young Leem ^a

Sol-gel dip-coating was used to grow ZnO thin films doped with various concentrations of B on quartz substrates. The effects of B doping on the absorption coefficient, optical band gap, Urbach energy, refractive index, average oscillator strength, average oscillator wavelength, moments M1 and M3, dielectric constant, optical conductivity, and electrical resistivity were investigated. Transmittance spectra showed that the BZO thin films had significantly higher transmittance than the ZnO thin films in the visible region of the spectrum and that the absorption edge.

5. Effect on structural, optical and electrical properties of aluminum-doped zinc oxide films using diode laser annealing

Author [links](#) [open](#) [overlay](#) [panel](#) Wen-Tse Hsiao ^a, Shih-Feng Tseng ^a, Chien-Kai Chung ^a, Donyau Chiang ^a

This study investigated the laser annealing characteristics of aluminum-doped zinc oxide (AZO) films using a diode laser source and moving stage with varying parameters. The results showed that varying the laser fluence and annealing speed affected the optical, electrical, and structural characteristics of the AZO films. The absorption band edge moved towards shorter or longer wavelengths, the optical energy band gap increased, the grain size increased, and the AFM-derived root mean square (RMS) values decreased.

6. Effect of Al doping on crystallography and electro-optical properties of ZnO semiconductor thin films prepared by electrospinning. [panel](#)

Soheila Osali ^a, Hamid Esfahani ^a, Hamidreza Karami ^b

This study investigated the microstructural and optical properties of nanocrystallite ZnO films fabricated using electrospinning and post-calcination, undoped and doped with aluminum. Results showed that doping ZnO with Al resulted in the Zn-O bond shifting towards higher energy levels, polarizing the visible lights more, and reducing the optical band gap energy. The electrical conductivity of ZnO film was improved by Al incorporation.

CHAPTER-3

AIM AND SCOPE

3.1 Aim:

The purpose of this project is to synthesize Dip-coated Aluminum-doped Zinc oxide thin films. We sought to comprehend the differences between Aluminum doped and AzO in terms of efficiency. To create the Aluminum-doped Zinc oxide thin film and characterized the film's properties. To cut down on the expense and preparation time, we decided to make FTO thin film using the Dip coating method. The primary emphasis of synthesis was the long-haul communication devices. X-Ray diffraction (XRD) is a non-destructive technique that provides crystallographic structure, chemical composition, and physical properties of a material. A UV-Visible spectrometer was used to evaluate optical properties. FTIR Spectroscopy, is an analytical technique used to identify organic, polymeric, and, in some cases, inorganic materials. Hall effect measurements were used to study electrical properties.

3.2 Scope:

Thin film technology has started to be used in commercial items as of the advent of the twenty-first century. Thin films have a wide range of uses and have proven crucial to many industrial and scientific activities over time. For cutting-edge applications in a variety of disciplines, including optical devices, environmental applications, telecommunications devices, energy storage devices, and others, thin films are regarded as the foundation. Data storage, thin-film solar cells, optoelectronic devices, and optical coating are some general categories under which thin-film applications might be categorized. Lithium-ion batteries with a thin layer. Therefore, we are utilizing fluorine doped tin oxide thin film to raise the solar cell's effectiveness.

Chapter – 4

Materials and Methodology

4.1 Materials

- I. Zinc Acetate dihydrate
- II. 2-Methoxyethanol
- III. Aluminum Nitrate Nonahydrate

I. Zinc Acetate dihydrate:

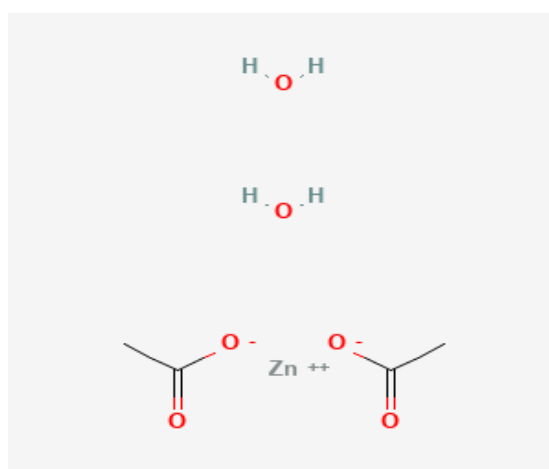


Fig 3.1 Zinc Acetate dihydrate structure

Chemical name	Zinc Acetate dihydrate
Chemical formula	$\text{Zn}(\text{CH}_3\text{COO})_2(\text{H}_2\text{O})_2$
Molar weight	219.51 g/mole
Boiling point	124 °C
Melting point	237 °C
Density	1.735 g/cm ³
IUPAC name	Zinc acetate
Solubility	Soluble in water and ethanol

Properties of Zinc Acetate dihydrate

Chemical compound, zinc ions (Zn^{2+}) coordinated with acetate ions (CH_3COO^-) and water molecules make up zinc acetate dihydrate ($\text{Zn}(\text{CH}_3\text{COO})_2 \cdot 2\text{H}_2\text{O}$). Chemically speaking, zinc ions (Zn^{2+}) coordinated with acetate ions (CH_3COO^-) and water molecules make up zinc acetate dihydrate ($\text{Zn}(\text{CH}_3\text{COO})_2 \cdot 2\text{H}_2\text{O}$). It is a white crystalline powder that is frequently used for a variety of purposes, including as dietary supplements, food preservation, chemical reaction catalysts, and pharmaceutical and medical formulations.

Zinc oxide (ZnO) or zinc carbonate (ZnCO_3) combine with acetic acid (CH_3COOH) or other sources of acetate to produce zinc acetate dihydrate. It has a melting point of about 237°C and a molar mass of about 219.5 g/mol . By heating the dihydrate form, which has two molecules of water per formula unit, anhydrous zinc acetate ($\text{Zn}(\text{CH}_3\text{COO})_2$) is produced.

Zinc oxide (ZnO) or zinc carbonate (ZnCO_3) combines with acetic acid (CH_3COOH) or other sources of acetate to produce zinc acetate dihydrate. It has a melting point of about 237°C and a molar mass of about 219.5 g/mol . By heating the dihydrate form, which has two molecules of water per formula unit, anhydrous zinc acetate ($\text{Zn}(\text{CH}_3\text{COO})_2$) is produced.

II. 2-Methoxyethanol:

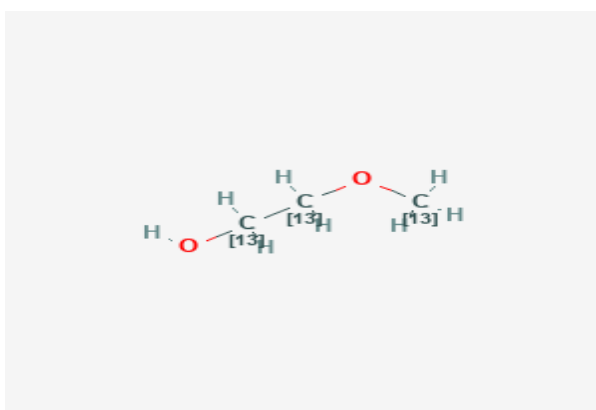


Fig 3.2 Methoxyethanol

Chemical name	2-Methoxy Ethanol
Chemical formula	CH ₃ OCH ₂ CH ₂ OH
Molar weight	76.1 g/mole
Boiling point	124 to 125 °C (255 to 257 °F; 397 to 398 K)
Melting point	-85.10 °C
Density	0.965 g/cm ³
IUPAC name	2-methoxyethanol
Solubility	miscible

Properties of 2-Methoxy ethanol

2-Methoxyethanol has the chemical formula CH₃OCH₂CH₂OH and is also referred to as methyl cello solve or ethylene glycol monomethyl ether. It has an odour that is slightly pleasant and is a clear, colorless liquid. Inks, cleaning products, paint and coating compositions, and other industrial uses all use 2-methoxyethanol as a solvent.

Additionally, it serves as a chemical intermediary in the synthesis of other molecules as well as a component in some antifreeze compositions. Due to its possible toxicity and detrimental effects on human health, it should be used cautiously. The skin, eyes, and respiratory system may become irritated after being exposed to 2-methoxyethanol and repeated or extended exposure may have more severe health impacts. Appropriate safety measures, such as sufficient ventilation and protective gear.

III. Aluminum Nitrate Nonahydrate:

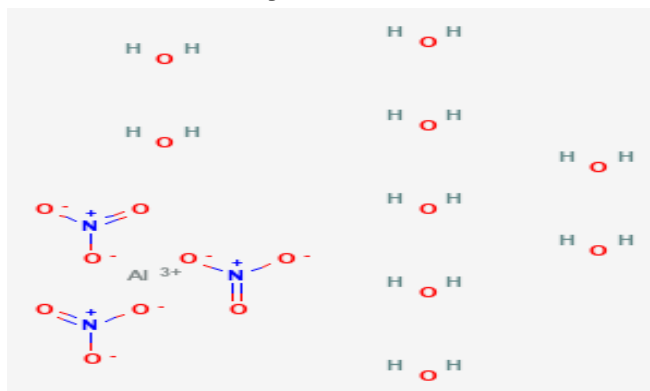


Fig 4.3 Aluminum Nitrate Nonahydrate

Chemical name	Aluminum Nitrate Monohydrate
Chemical formula	$\text{Al}(\text{NO}_3)_3 \cdot \text{H}_2\text{O}$
Molar weight	236.15 g/mole
Boiling point	135 °C
Melting point	Decomposes above 150°C
Density	1.72 g/cm ³
IUPAC name	aluminum;trinitrate;nonahydrate
Solubility	Soluble in water, ethanol, and methanol

Properties of Aluminum Nitrate Nonahydrate

$\text{Al}(\text{NO}_3)_3 \cdot \text{H}_2\text{O}$, commonly known as aluminum nitrate monohydrate, is a chemical combination made up of aluminum (Al^{3+}) and nitrate (NO_3^-) ions coupled with a water molecule (H_2O) as a hydrate. It is a tasteless, colorless, crystalline substance.

Common industrial and laboratory uses for aluminum nitrate monohydrate include the creation of ceramics, dyes, and catalysts.

Additionally, certain antiperspirants and personal care products contain it as a component as well as using it as a mordant in textile dyeing. The substance dissolves in water and turns into a transparent solution. It is a dangerous compound since it is a potent oxidizing agent and can react with reducing agents or flammable substances. When working, proper handling, storage, and disposal procedures should be taken.

4.2 Methodology

4.2.1 Dip coating principle

Dip coating is a process in which an object or substrate is dipped into a liquid coating material, such as paint, polymer, or other liquid solution, to form a thin, even coating on its surface. The object is typically pre-treated or cleaned before the dipping process to ensure proper adhesion of the coating. Once dipped, the object is then withdrawn from the coating material, allowing excess liquid to drain off, and the coating material is allowed to dry or cure, forming a solid coating. Dip coating is commonly used in various industries for applications such as protective coatings, surface finishing, and product enhancement, and it is often chosen for its simplicity, cost-effectiveness, and ability to coat complex shapes or substrates.

Analyze results: Analyze the results obtained from the dip coating experiment, and interpret the findings in the context of your research or application. Draw conclusions and make any necessary adjustments for future experiments or applications.

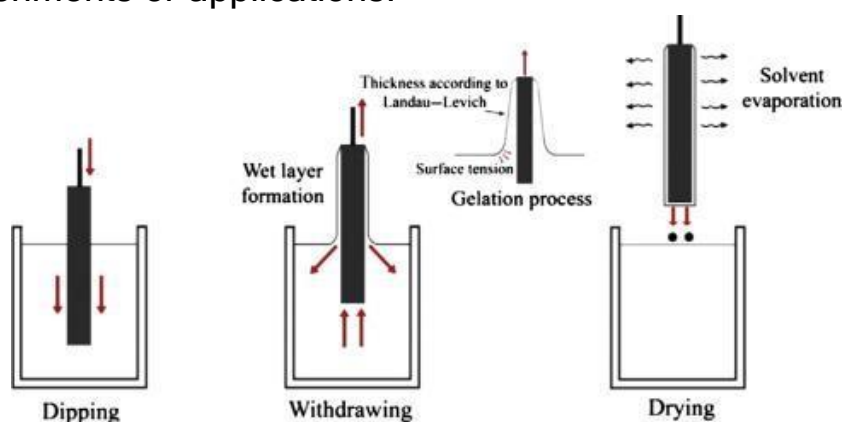


Fig 3.4 Dip coating

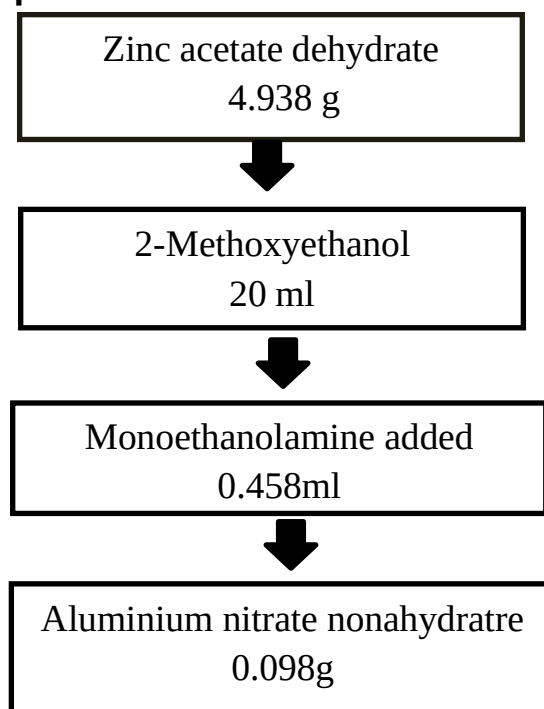
4.2.2 Dip coating process description substrate cleaning:

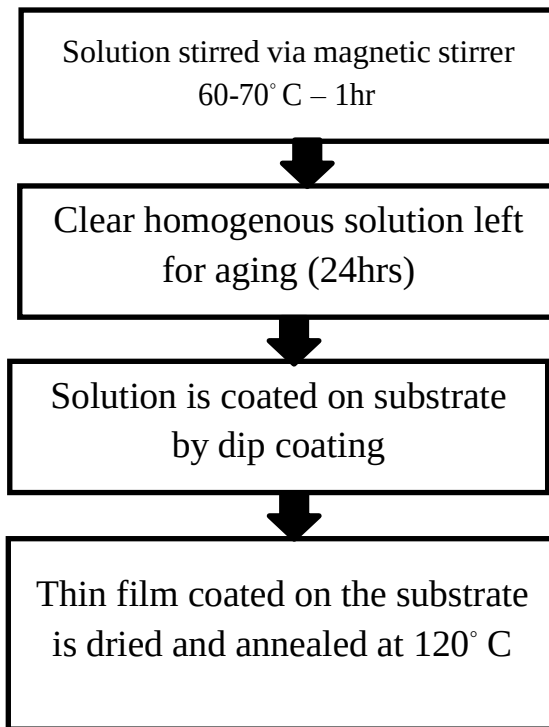
Substrate cleaning is a crucial step in the dip coating process. It involves removing contaminants from the surface of the object or substrate that will be dipped into the coating material. Methods for substrate cleaning can include mechanical scrubbing or sanding, chemical cleaning with solvents or cleaners, or surface treatment with plasma, corona, or chemical agents. Thorough rinsing and drying of the substrate are performed after cleaning to ensure proper adhesion of the coating material.

4.3 Experimental Procedure for Doped AzO:

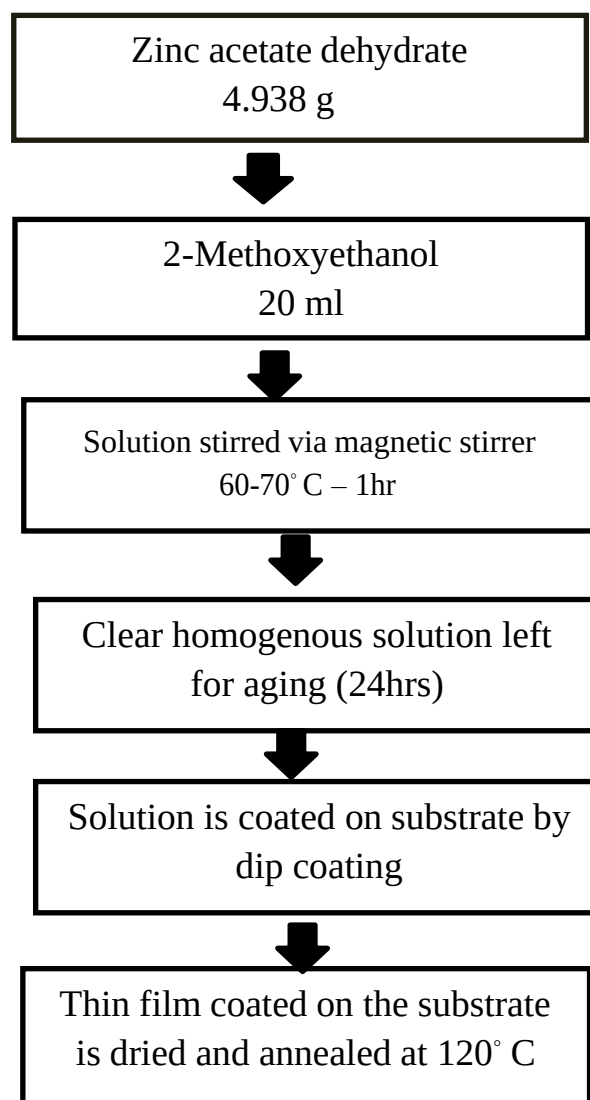
The experimental process for doped AzO materials usually entails creating the material using methods like sol-gel synthesis or solid-state reactions, analyzing the data collected, and then characterizing the material's crystal structure, morphology, chemical composition, and optical properties. This entails contrasting the outcomes with reference materials, interpreting the results, and analyzing them in light of the study's goals and pertinent academic literature. The experimental process should be conducted with the appropriate safety safeguards in place.

Doped AzO doped flow chart:





Undoping Flow chart:



4.3 Application:

Dip coating is a versatile coating process used in various industries. It finds applications in automotive for corrosion protection, medical devices for biocompatibility, electronics for environmental protection, aerospace for wear and heat resistance, optics for optical performance, industrial coatings for performance enhancement, consumer goods for decorative coatings, cosmetics and personal care for aesthetic appeal, energy for performance improvement, and food processing for non-stick coatings. Dip coating offers advantages such as uniform coating thickness, ease of application, and versatility, making it a popular choice in many coating applications.

4.4 Dip coating, Advantage and Drawbacks:

Dip coating has several advantages, including:

Simplicity: Dip coating is a simple and easy-to-understand process that requires minimal equipment and training.

Cost-effectiveness: Dip coating is a cost-effective way to apply coatings to large numbers of objects or substrates.

Ability to coat complex shapes: Dip coating can coat complex shapes or substrates that are difficult to coat using other methods.

However, dip coating also has some drawbacks, including:

Limited coating thickness: Dip coating is generally limited to producing thin coatings, as the excess coating material drips off during withdrawal.

Limited control over coating thickness: It can be challenging to achieve precise control over the thickness of the coating using dip coating.

Limited variety of coating materials: The range of coating materials that can be used in dip coating are limited to those that can be applied as a liquid and that will adhere to the substrate.

Chapter-5

Results and discussion

5.1 XRD (X-Ray diffraction)

X-ray diffraction (XRD) is a technique used to analyze the crystal structure of materials. It involves the use of X-rays to determine the arrangement of atoms in a material by measuring the diffraction pattern produced when the X-rays interact with the material. The XRD data obtained from a sample can provide information about the crystal structure, lattice parameters, and the orientation of crystalline domains in the material. To perform XRD analysis, a sample is exposed to a beam of X-rays at a specific angle and the resulting diffraction pattern is recorded on a detector. The angle at which the X-rays are diffracted depends on the spacing between the crystal planes in the sample. By analyzing the positions and intensities of the diffracted X-rays, it is possible to determine the crystal structure and properties of the material.

Some of the important parameters that can be obtained from XRD data include the crystal phase and its purity, the crystal orientation and grain size, lattice parameters, and inter planar spacing. The XRD data can be analyzed using software programs to generate a diffraction pattern and calculate the relevant parameters.

In a project thesis, XRD data can be presented in the form of graphs or tables, along with a detailed explanation of the analysis performed and the results obtained. The XRD analysis should be properly documented, including details of the equipment used, sample preparation methods, and measurement conditions. The interpretation of the XRD data should be supported by appropriate literature references, and the limitations of the analysis should also be discussed. Overall, XRD analysis is an important tool for characterizing the crystal structure and properties of materials and can provide valuable insights for research projects.

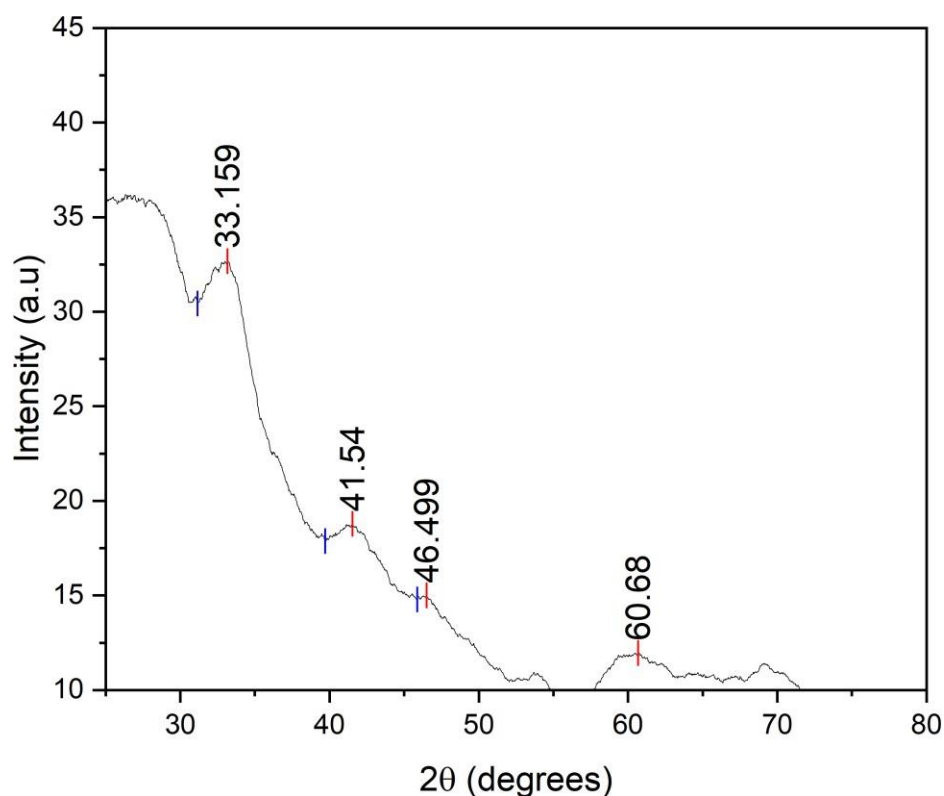


Fig 5.1 XRD Pattern of the AZO

The XRD pattern of the AzO is shown in Figure 5.1. The peaks at 2θ values of 33.15° , 41.54° , 46.49° , 60.68° can be associated with (1 1 0), (2 1 1), (0 0 2), (321), respectively. The X-ray diffraction pattern revealed that the as deposited film had tetragonal crystal structure with preferable orientation along (110) plane. Which are in good agreement with the literature values (JCPDS card no. 41-1445)

5.2 UV-Visible Spectroscopy

UV-Visible spectroscopy is a technique used to study the interaction of molecules with light in the UV and visible regions of the electromagnetic spectrum. This technique is commonly used in research projects and to analyze the absorption and transmission of light by a sample, which can provide information about the electronic structure and properties of the molecules.

To perform UV-Visible spectroscopy, a sample is exposed to a beam of light with a range of wavelengths in the UV-Visible region. The amount of light absorbed by the sample is measured by a detector, and a spectrum of the sample is generated.

The extinction coefficient, which indicates the strength of the absorption, the molar absorptivity, which is a measure of the efficiency of the absorption, and the absorption spectrum, which shows the wavelengths of light absorbed by the sample, are some of the significant parameters that can be obtained from UV-Visible spectroscopy. UV-Visible spectroscopy data can be provided as graphs or tables in a project thesis together with a thorough description of the investigation carried out and the outcomes attained. The limits of the analysis should also be discussed, and the interpretation of the findings should be backed by pertinent literature references. Documentation of the sample preparation procedures and measurement circumstances is also necessary.

Overall, UV-Visible spectroscopy is a valuable tool for characterizing the electronic structure and properties of molecules, and can provide useful information for research projects and in a variety of fields, including chemistry, biochemistry, and materials science.

Absorbance Graph

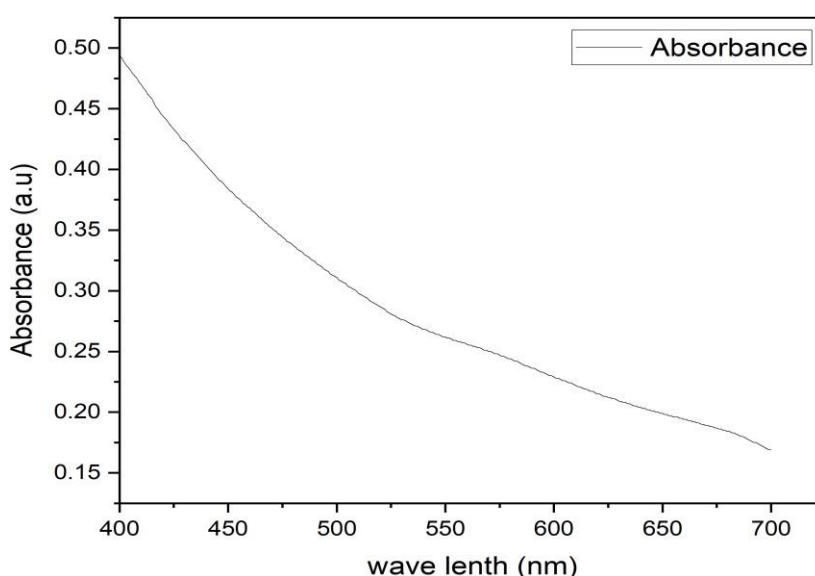


Fig 5.2 Absorbance of Pure ZnO

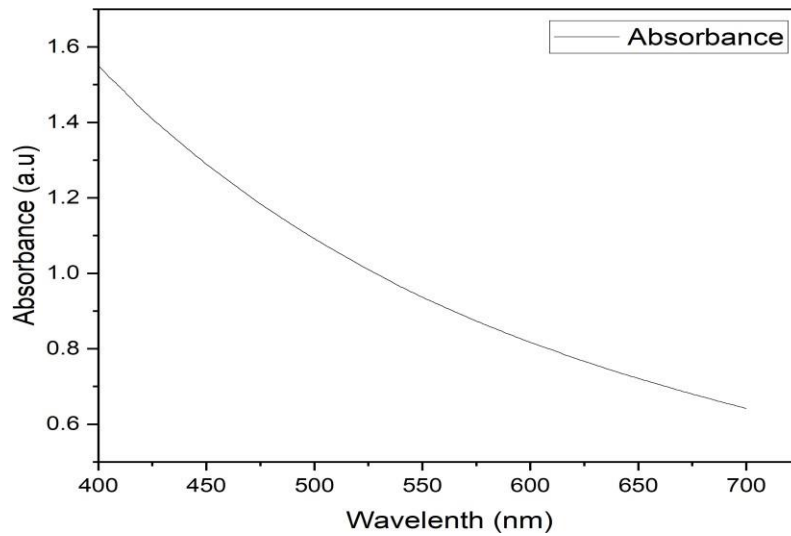


Fig 5.3 Absorbance of AzO

The absorbance spectrum of Pure AzO solution and Thin Film has been obtained by using UV-Vis Spectroscopy technique. The figure 5.2 illustrates that the maximum absorbance of Pure ZnO solution is about between (0.45-0.50a.u). The figure 5.3 illustrates that that maximum absorbance of AzO thin film is about between (1.4-1.5 a.u) ZnO solution has maximum at 405 nm cut-off frequency. AzO thin has maximum at 401 nm cut-off frequency, which indicates that both samples absorb maximum radiation in the UV region and decrease gradually in the visible region. We know that in the day time, the Earth's surface receives more UV radiation from the sun than the night (receive IR radiation). Therefore, AzO Thin film is suitable for long haul devices. Also, it has good agreements (C. Agashe et al (2009)).

5.3 Hall effect

The Hall Effect is a phenomenon in which a magnetic field applied perpendicular to an electric current in a conductor causes a transverse voltage to develop across the conductor. The Hall Effect is used in many research projects and theses to measure the properties of materials, such as the carrier concentration, mobility, and conductivity. To perform Hall Effect measurements, a sample is placed in a magnetic field perpendicular to a current flowing through the sample. The magnetic field causes the charged carriers to deflect, resulting in a voltage

perpendicular to both the current and the magnetic field. This voltage is known as the Hall voltage, and its magnitude is proportional to the strength of the magnetic field, the current density, and the carrier concentration.

From the Hall voltage, the carrier concentration, mobility, and conductivity can be calculated using mathematical formulas and assumptions about the material's physical properties. The carrier concentration is related to the Hall coefficient, which is the ratio of the Hall voltage to the product of the magnetic field strength and the current density. The mobility is related to the carrier concentration and the conductivity, which can be measured independently using other techniques.

In a brief project, Hall Effect measurements can be presented in the form of graphs or tables, along with a detailed explanation of the analysis performed and the results obtained the limitations of the analysis should also be discussed. The sample preparation methods and measurement conditions should also be documented.

Overall, Hall effect measurements are a valuable tool for characterizing the electronic properties of materials, and can provide useful information for research projects and in a variety of fields, including physics, materials science, and electrical engineering.

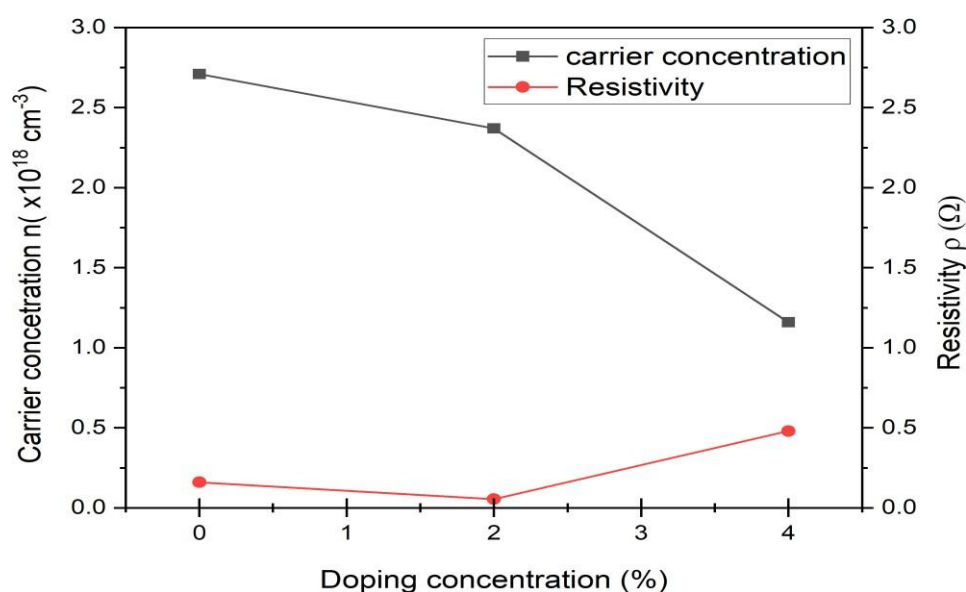


Fig 5.4 Carrier concentration and Resistivity

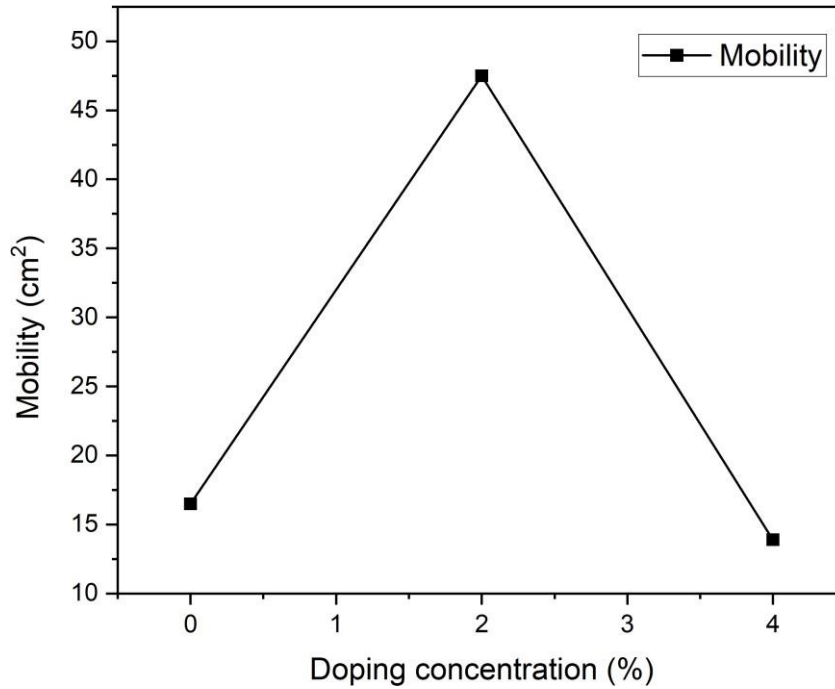


Fig 5.5 Mobility

No significant changes in the electrical properties of the film were observed in terms of the Spin RPM, The carrier concentration 1.3cm^3 and the mobility is $4.6\text{cm}^3/\text{s}$. The Resistivity value is 0.5-cm or the sample. Thus, the carrier concentration and resistivity values show the good conductivity nature of doped zinc oxide thin film. Fig 5.4 and 5.5 shows that variation in the carrier concentration and mobility of AZO thin film as a function of the Spin RPM and the variation in the resistivity and the average hall coefficient of the AZO film as a function of spin RPM respectively.

CHAPTER – 6

CONCLUSION

In this brief report, we examined the electro-optical properties of the specimens. PL spectra from the ZnO film and ZnO:Al film are shown in Figures. The studies that can be taken us XRD (X-Ray diffraction), UV-Visible spectroscopy, Hall effect (Carrier concentration, Resistivity and Mobility) are be studied. The XRD values are peaks at 2θ values of 33.15° , 41.54° , 46.49° , 60.68° can be associated with (1 1 0), (2 1 1), (0 0 2), (321) respectively. The UV-Visible spectroscopy that maximum absorbance of Pure ZnO solution is about between (0.45-0.50a.u). The maximum absorbance of AzO thin film is about between (1.4-1.5 a.u) pure ZnO solution has maximum at 405 nm cut-off frequency. AzO thin has maximum at 401 nm cut-off frequency. In Hall Effect, the carrier concentration 1.3cm^3 and the mobility is $4.6\text{cm}^3/\text{s}$. The Resistivity value is 0.5-cm or the sample. Thus, the carrier concentration and resistivity values show the good conductivity nature of doped zinc oxide thin film.

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LIST OF CONFERENCE

AUTHORS	Conferences	Date	Title	Presentation
D. Santhosh	Centre for Advanced Materials Research (CAMR)	27/04/2023	Next Generation Energy Storage Devices	Oral Presentation on 27/04/2023
D. Santhosh	FTIR	28/03/2023	National Workshop on FTIR	Oral Presentation on 28/03/2023

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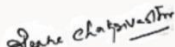

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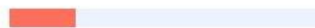
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