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*Research Article*

# Chemical Bath Deposition Method for The Synthesis and Characterisation of Thin Films

**Dr. Dipak Ashok Zope** [1*], **Prof. Yogesh B. Patil** [2], **Prof. Nitin A. Kharche** [3], **Bharati M. Nimbolkar** [4]
[1,2,3,4] Assistant Professor, Padm. Dr. V. B. Kolte College of Engineering, Malkapur, Buldhana
Maharashtra, India

**Corresponding Author:** * Dr. Dipak Ashok Zope

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## Abstract

Thin film technology plays a crucial role in modern electronics, optoelectronics and photovoltaic applications. Among various fabrication techniques, Chemical Bath Deposition (CBD) has emerged as a simple, cost-effective and scalable method for the preparation of high-quality thin films. This research paper presents the synthesis and characterisation of thin films prepared using the CBD method. The study focuses on optimising deposition parameters such as temperature, pH, concentration and deposition time. The structural, optical and electrical properties of the deposited films are analysed using standard characterisation techniques. The results indicate that CBD-grown thin films exhibit good crystallinity, uniform morphology and suitable optical properties for device applications.

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**KEYWORDS:** Thin Films, Chemical Bath Deposition, CBD Method, Semiconductor Materials, Optical Properties, Photovoltaic Applications.

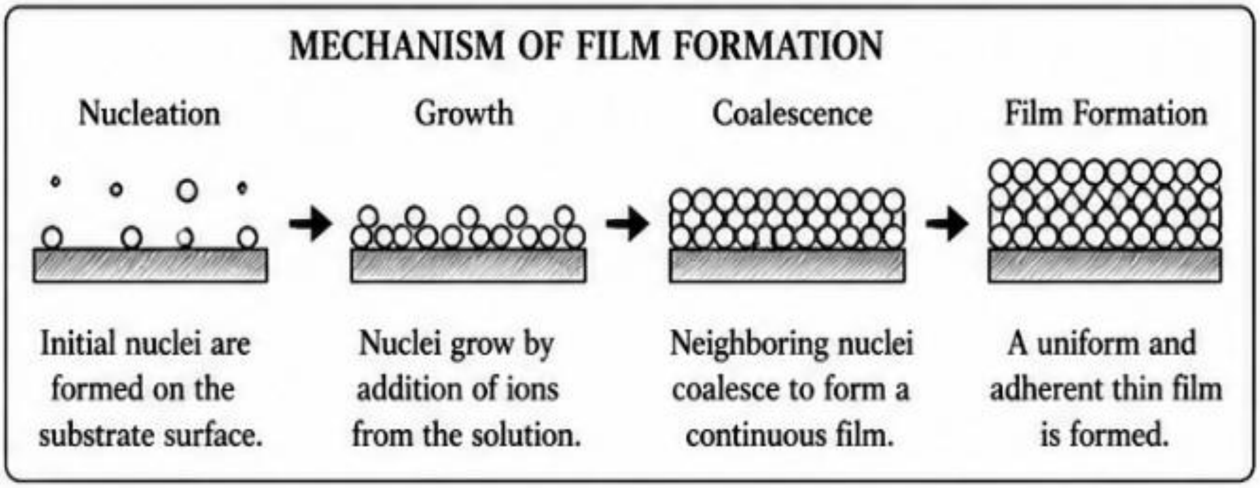
## 1. INTRODUCTION

Thin films are layers of material with thickness ranging from a few nanometres to several micrometres and are widely used in electronic, optical and energy-related devices [5]. These films are essential in applications such as solar cells, sensors, integrated circuits and optical coatings due to their tunable physical properties [13]. The rapid advancement in semiconductor technology has increased the demand for low-cost and scalable fabrication techniques [6].

In modern engineering applications, thin films play a significant role in improving device efficiency and performance. For instance, in photovoltaic devices, thin films act as absorber layers that convert solar energy into electrical energy [14]. Their reduced thickness allows better control over charge transport and recombination processes, thereby enhancing device efficiency [28]. Additionally, thin films are widely used in anti-reflective coatings and optical filters due to their ability to manipulate light at the nanoscale [17].

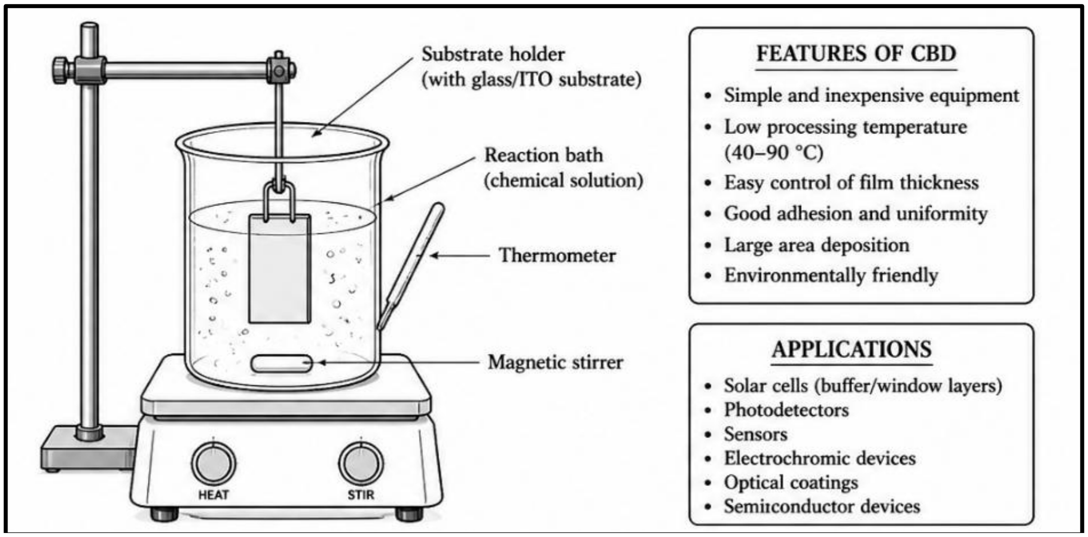
Chemical Bath Deposition (CBD) is a solution-based technique that enables controlled growth of thin films through chemical reactions occurring in an aqueous medium [7]. In this method, substrates are immersed in a chemical bath containing metal ions and chalcogenide sources, leading to the formation of a thin film via ion-by-ion condensation [25]. The process is governed by parameters such as temperature, pH, concentration and deposition time, which directly influence film properties such as thickness, crystallinity and morphology [14].

The growth mechanism in CBD involves the controlled release of ions in the solution, which react near the substrate surface to form a solid phase [4]. Complexing agents are often used to regulate the availability of metal ions, preventing rapid precipitation and ensuring uniform film formation [20]. This controlled nucleation and growth process results in films with good adhesion and uniformity [8].



CBD is particularly advantageous due to its simplicity, low equipment cost and ability to deposit films over large areas [9]. Unlike vacuum-based techniques such as sputtering or evaporation, CBD does not require sophisticated instrumentation, making it suitable for large-scale industrial applications [23]. Furthermore, the method allows deposition at relatively low temperatures, which is beneficial for flexible and temperature-sensitive substrates [26].

Another important aspect of CBD is its adaptability to different materials systems. A wide range of semiconductor materials such as CdS, ZnS, PbS and metal oxides can be synthesised using this technique [16]. This versatility makes CBD a preferred method in research and industrial applications, especially in the field of optoelectronics and renewable energy [38].



Despite its advantages, CBD also presents certain challenges such as control over film stoichiometry, reproducibility and impurity incorporation [27]. Researchers are continuously working on optimising process parameters and developing hybrid techniques to overcome these limitations [33].

Therefore, the present study focuses on the synthesis and characterisation of thin films using the CBD method, aiming to understand the influence of deposition parameters on film properties and their suitability for advanced technological applications [10].

## 2. LITERATURE REVIEW

Numerous studies have demonstrated the effectiveness of Chemical Bath Deposition (CBD) in producing high-quality thin films for semiconductor and photovoltaic applications [4]. Early investigations primarily focused on cadmium sulfide (CdS) thin films, which have been extensively used as window layers in solar cells due to their suitable direct band gap (~2.42 eV) and high optical transparency in the visible region [15]. These pioneering studies established that CBD is capable of producing uniform, adherent and pinhole-free films with good optical and structural properties [7]. The simplicity and low cost of the CBD process made it highly attractive for large-area deposition and commercial-scale applications.

Further research explored the influence of deposition parameters such as precursor concentration, bath temperature, pH and deposition time on the quality of CdS thin films [14]. It was observed that slight variations in these parameters significantly affect nucleation, growth rate and crystallinity of the films. For instance, higher bath temperatures generally enhance crystallinity, whereas pH plays a crucial role in controlling ion release and film thickness [20]. These findings highlighted the importance of process optimisation in achieving desired film characteristics.

Subsequent studies extended the CBD technique to other semiconductor materials such as zinc sulfide (ZnS), lead sulfide (PbS) and cadmium selenide (CdSe) [16]. ZnS thin films, with a wide band gap (~3.6 eV), are widely used in optoelectronics. devices and as buffer layers in solar cells due to their non-toxic nature and high transparency [28]. PbS thin films, on the other hand, have a narrow band gap and are suitable for infrared detectors and photoconductive applications. Researchers reported that CBD-grown PbS films exhibit excellent photoconductivity and strong absorption in the infrared region [31].

In addition to binary compounds, ternary and quaternary thin films have also been synthesised using CBD to enhance device performance. These materials provide better control over band gap engineering and carrier transport properties [32]. Studies have shown that alloying and doping techniques can significantly modify the electrical conductivity and optical absorption characteristics of thin films [33]. For example, doping CdS thin films with elements such as Al, In, or Cu improves their electrical properties and enhances their suitability for photovoltaic applications [9].

Another important area of research involves the study of growth mechanisms in CBD. It has been reported that thin film formation occurs through two primary mechanisms: ion-by-ion condensation and cluster-by-cluster deposition [4]. The dominance of either mechanism depends on the concentration of ions and the presence of complexing agents in the solution. Controlled release of ions through complexation ensures uniform nucleation and growth, resulting in high-quality films with good adhesion [25].

Researchers have also investigated the structural, morphological and optical characterisation of CBD-grown thin films using advanced techniques such as X-ray diffraction (XRD), scanning electron microscopy (SEM) and UV-Visible spectroscopy [19]. XRD studies reveal the crystalline nature and phase purity of the films, while SEM analysis provides insights into surface morphology and grain size distribution [30]. Optical studies, particularly using Tauc plots, are widely used to determine the optical band gap of the films [20].

Recent advancements in nanotechnology have led to the development of nanostructured thin films using the CBD method [9]. These nanostructures exhibit enhanced surface area, improved charge transport and superior optical properties, making them highly suitable for applications in sensors, photodetectors and solar cells. Additionally, multilayer thin film structures have been developed to improve device efficiency by optimising light absorption and charge separation [38].

Another emerging trend is the use of CBD in flexible and wearable electronics. Due to its low-temperature processing capability, CBD is compatible with polymer substrates, enabling the fabrication of flexible thin film devices [26]. This has opened new avenues in the development of next-generation electronic devices.

Despite its advantages, several challenges remain in the CBD process. Issues such as poor reproducibility, impurity incorporation and difficulty in controlling stoichiometry have been reported [27]. Researchers are actively working on improving process control and developing hybrid deposition techniques to overcome these limitations [33].

Overall, the literature clearly indicates that CBD is a versatile, cost-effective and scalable technique for thin film synthesis. Continuous research efforts are focused on improving film quality, exploring new material systems and expanding the range of applications in advanced technologies [17].

## 3. METHODOLOGY

Numerous researchers have explored the CBD method for thin film deposition. Studies have shown that CBD is effective for producing uniform and adherent films [11]. Early work demonstrated the deposition of CdS thin films for photovoltaic applications [12]. Later studies focused on ZnS and PbS films for optoelectronic devices [13].

Researchers have also investigated the influence of bath composition, pH and temperature on film growth [14]. It has been observed that deposition parameters significantly affect the crystallinity and morphology of thin films [15]. Recent advancements include the use of CBD for nanostructured thin films and doping techniques to enhance electrical conductivity [16].

The literature indicates that CBD remains a promising method due to its simplicity, low cost and scalability [17].

### 3.1 Materials

- Metal salt precursors
- Complexing agents
- Substrates (glass/ITO)
- Distilled water

Metal Salt Precursors: Metal salt precursors act as the primary source of metal ions required for thin film formation. Commonly used precursors include cadmium chloride ($CdCl_2$), zinc sulfate ($ZnSO_4$) and lead acetate ($Pb(CH_3COO)_2$), depending on the desired thin film material [4]. These salts dissociate in aqueous solution to release metal ions, which subsequently react with chalcogenide ions to form the thin film. The concentration of these precursors significantly influences nucleation rate, film thickness and crystallinity [14].

- Complexing Agents: Complexing agents such as ammonia ($NH_3$), triethanolamine (TEA), or ethylenediaminetetraacetic acid (EDTA) are used to control the release of free metal ions in the solution [25]. These agents form stable complexes with metal ions, preventing rapid precipitation and ensuring a controlled and gradual deposition process. This controlled ion release is essential for obtaining uniform, adherent and high-quality thin films [20].
- Substrates (Glass/ITO): Substrates provide the surface on which thin films are deposited. Common substrates include microscopic glass slides and indium tin oxide (ITO)-coated glass [23]. Glass substrates are widely used due to their smooth surface, transparency and chemical stability, whereas ITO substrates are preferred for optoelectronic applications due to their electrical conductivity and optical transparency [28]. Proper cleaning of substrates is essential to remove contaminants and ensure good adhesion of the deposited film [21].
- Distilled Water: Distilled or deionised water is used as the solvent for preparing the chemical bath solution. It ensures the absence of unwanted impurities and ions that could interfere with the deposition process [27]. The purity of water directly affects the chemical reactions, film uniformity and overall quality of the thin films.
- The careful selection and control of these materials are essential for achieving reproducible results and optimising the structural, optical and electrical properties of the deposited thin films [33].

### 3.2 Experimental Setup

The Chemical Bath Deposition (CBD) setup consists of a reaction bath, temperature control system and substrate holder, designed to facilitate controlled thin film growth under optimised conditions [18]. The experimental arrangement is simple, cost-effective and suitable for laboratory as well as large-scale deposition processes.

The reaction bath is typically a glass beaker or container capable of withstanding moderate temperatures and chemical reactions. It contains the aqueous solution of metal salt precursors, complexing agents and chalcogenide sources. The volume of the bath and concentration of reactants are carefully selected to maintain uniform deposition conditions throughout the experiment [25].

A temperature control system, such as a thermostatically controlled water bath or hot plate with magnetic stirrer, is used to maintain a constant temperature during the deposition process. Temperature is a critical parameter as it influences the rate of chemical reactions, nucleation and growth of thin films [14]. Maintaining a stable temperature ensures reproducibility and uniformity of the deposited films.

The substrate holder is used to position the substrates vertically or at a slight angle inside the reaction bath. Proper orientation of the substrate is essential to ensure uniform film deposition on its surface. The holder is usually made of inert materials to avoid contamination of the chemical bath [23].

In addition to these basic components, stirring mechanisms are often employed to maintain homogeneity of the solution and prevent localised precipitation [20]. Continuous stirring ensures the uniform distribution of ions and enhances the quality of the deposited thin film.

Before deposition, substrates are thoroughly cleaned using standard cleaning procedures involving detergent washing, distilled water rinsing and drying. This step is essential to remove impurities and improve adhesion of the thin film [21].

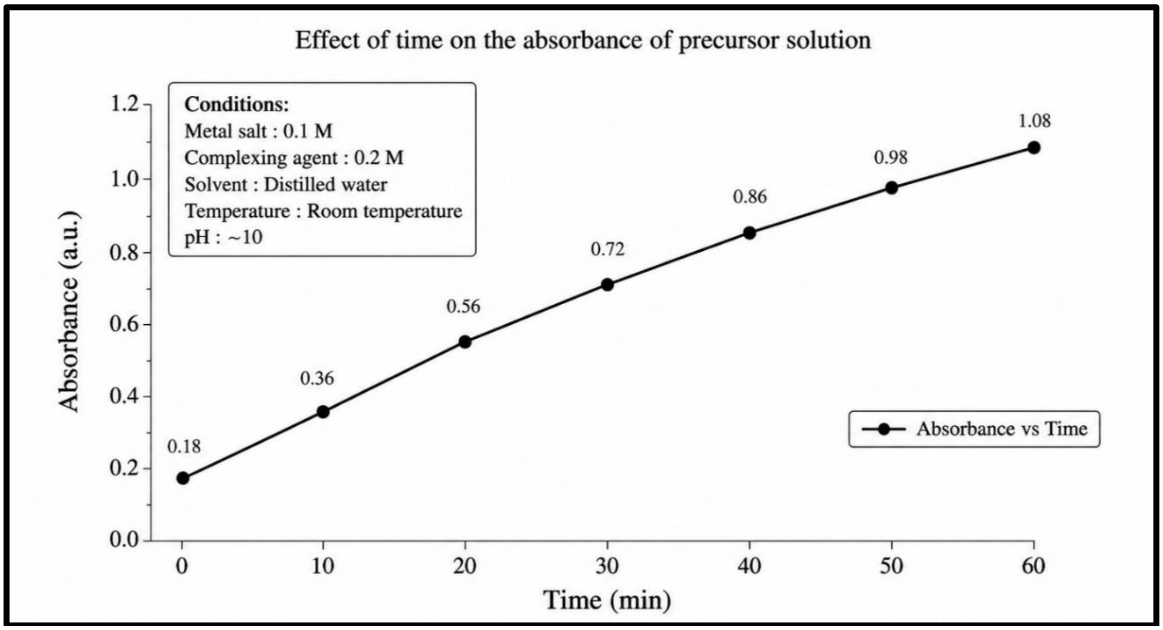
Overall, the CBD experimental setup provides a controlled environment for thin film growth, allowing precise adjustment of deposition parameters such as temperature, pH and concentration, which ultimately determine the structural and optical properties of the films [33].

### 3.3 Deposition Process

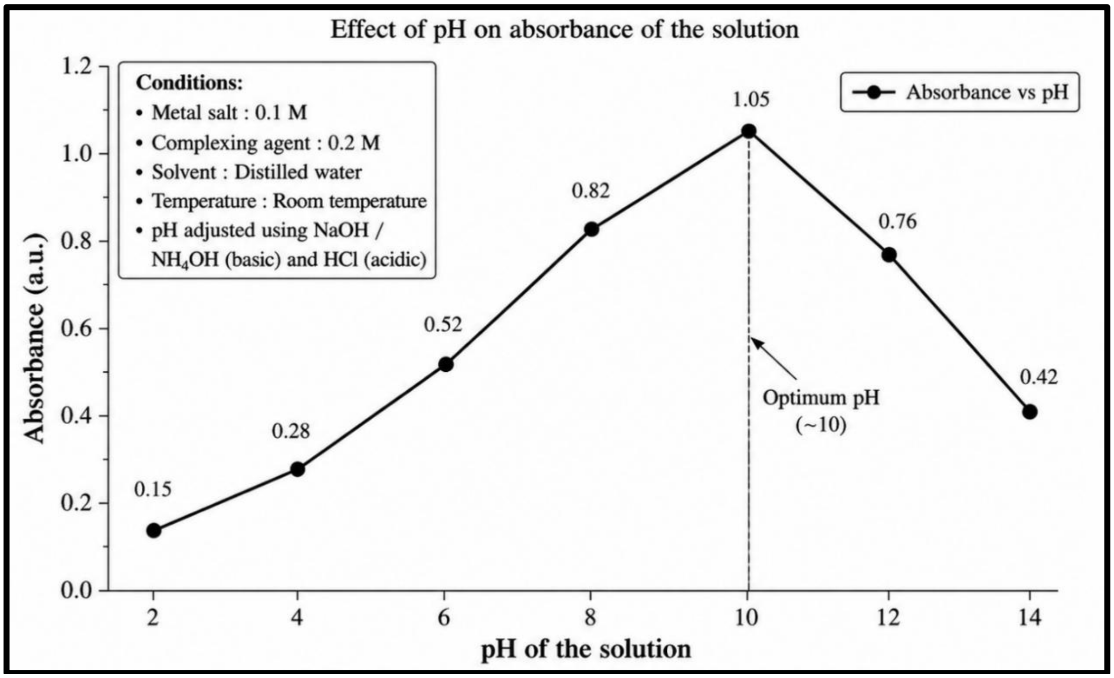
1. Preparation of precursor solution [19]
2. Adjustment of pH using suitable agents [20]
3. Immersion of cleaned substrates [21]
4. Deposition at controlled temperature [22]

The deposition of thin films using the Chemical Bath Deposition (CBD) method involves a sequence of well-controlled steps to ensure uniform film growth and desired material properties. The detailed procedure is described as follows:

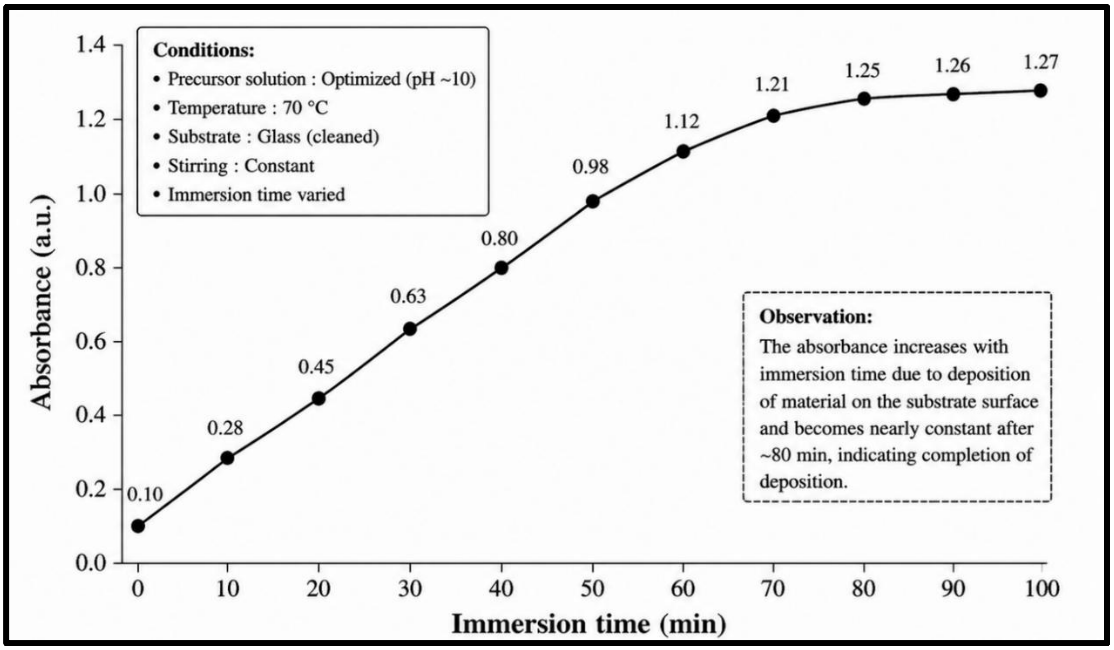
1. Preparation of Precursor Solution: The precursor solution is prepared by dissolving appropriate metal salt precursors in distilled water under continuous stirring to obtain a homogeneous solution [19]. The concentration of the solution is carefully controlled as it directly influences the nucleation rate and thickness of the deposited thin film. In addition, a suitable chalcogenide source (such as thiourea for sulfide films) is added to supply the required anions for film formation.



2. Adjustment of pH Using Suitable Agents: The pH of the solution is adjusted using complexing agents such as ammonia ($NH_3$) or triethanolamine (TEA) to control the release of free metal ions [20]. The pH plays a critical role in determining the rate of chemical reaction and the stability of the solution. Proper pH adjustment prevents rapid precipitation in the bulk solution and promotes controlled deposition on the substrate surface.

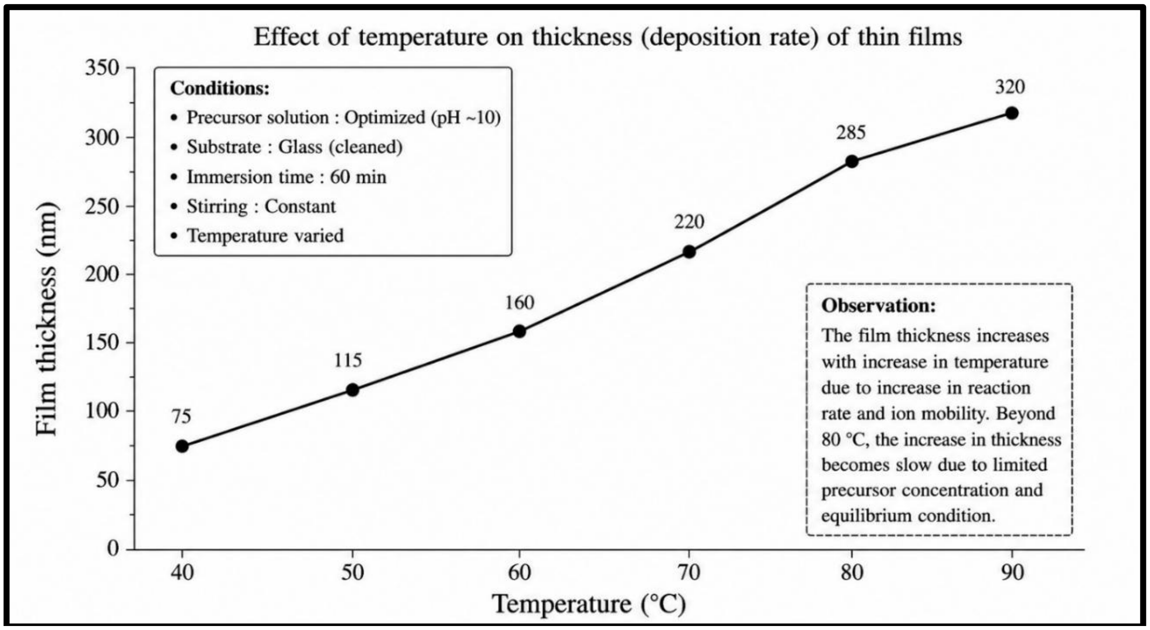


3. Immersion of Cleaned Substrates: The thoroughly cleaned substrates (glass or ITO-coated glass) are vertically immersed in the prepared chemical bath [21]. Proper cleaning ensures the removal of contaminants, leading to better adhesion and uniformity of the thin film. The orientation of the substrate is maintained carefully to achieve even deposition over the entire surface.



4. Deposition at Controlled Temperature: The chemical bath is maintained at a constant temperature, typically in the range of 50–80 °C, using a temperature control system [22]. Temperature significantly affects the kinetics of the reaction, ion mobility and growth rate of the thin film. Under controlled conditions, ions react near the substrate surface, resulting in nucleation and subsequent growth of the thin film.

The overall deposition process involves nucleation, growth and coalescence of particles on the substrate surface, leading to the formation of a uniform and adherent thin film. Careful control of each step is essential for achieving reproducible and high-quality thin films suitable for various applications [33].



### 3.4 Characterization Techniques

- X-ray Diffraction (XRD) [24]
- UV-Visible Spectroscopy [25]
- Scanning Electron Microscopy (SEM) [26]
- Electrical measurements [27]

The characterisation of thin films is essential to evaluate their structural, optical, morphological and electrical properties. In the present study, several standard techniques are employed to analyse the deposited thin films in detail.

- **X-ray Diffraction (XRD):** X-ray diffraction is used to determine the crystalline structure, phase identification and grain size of the deposited thin films [24]. The diffraction pattern is obtained by directing monochromatic X-rays onto the film surface and measuring the intensity of reflected rays at different angles. The obtained peaks are compared with standard data to identify crystal structure and phase purity. The average crystallite size (D) can be estimated using the Scherrer formula:

$D = (0.9\ \lambda) / (\beta\ \cos\theta)$

where $\lambda$ is the wavelength of X-rays, $\beta$ is the full width at half maximum (FWHM), and $\theta$ is the Bragg angle. XRD analysis provides important insights into crystallinity and structural quality of the films [19].

- **UV-Visible Spectroscopy:** UV-Visible spectroscopy is used to study the optical properties of thin films, including absorbance, transmittance and optical band gap [25]. The absorption spectrum is recorded over a range of wavelengths, and the band gap is determined using Tauc's relation. The optical band gap (Eg) is calculated by plotting $(\alpha h\nu)^2$ versus photon energy ($h\nu$) and extrapolating the linear portion to the energy axis [20]. This technique is crucial for evaluating the suitability of thin films for optoelectronic and photovoltaic applications [31].
- **Scanning Electron Microscopy (SEM):** SEM is employed to examine the surface morphology and microstructure of the thin films [26]. It provides high-resolution images that reveal grain size, surface uniformity, porosity and film coverage. SEM analysis helps in understanding the growth mechanism and quality of the deposited films [30].
- **Electrical Measurements:** Electrical properties such as resistivity, conductivity and carrier concentration are measured using standard techniques like the four-probe method [27]. These measurements provide information about charge transport behaviour in the thin films. Electrical characterisation is important for determining the applicability of thin films in electronic and photovoltaic devices [32].

The combination of these characterisation techniques provides a comprehensive understanding of the physical properties of thin films and their correlation with deposition parameters [33].

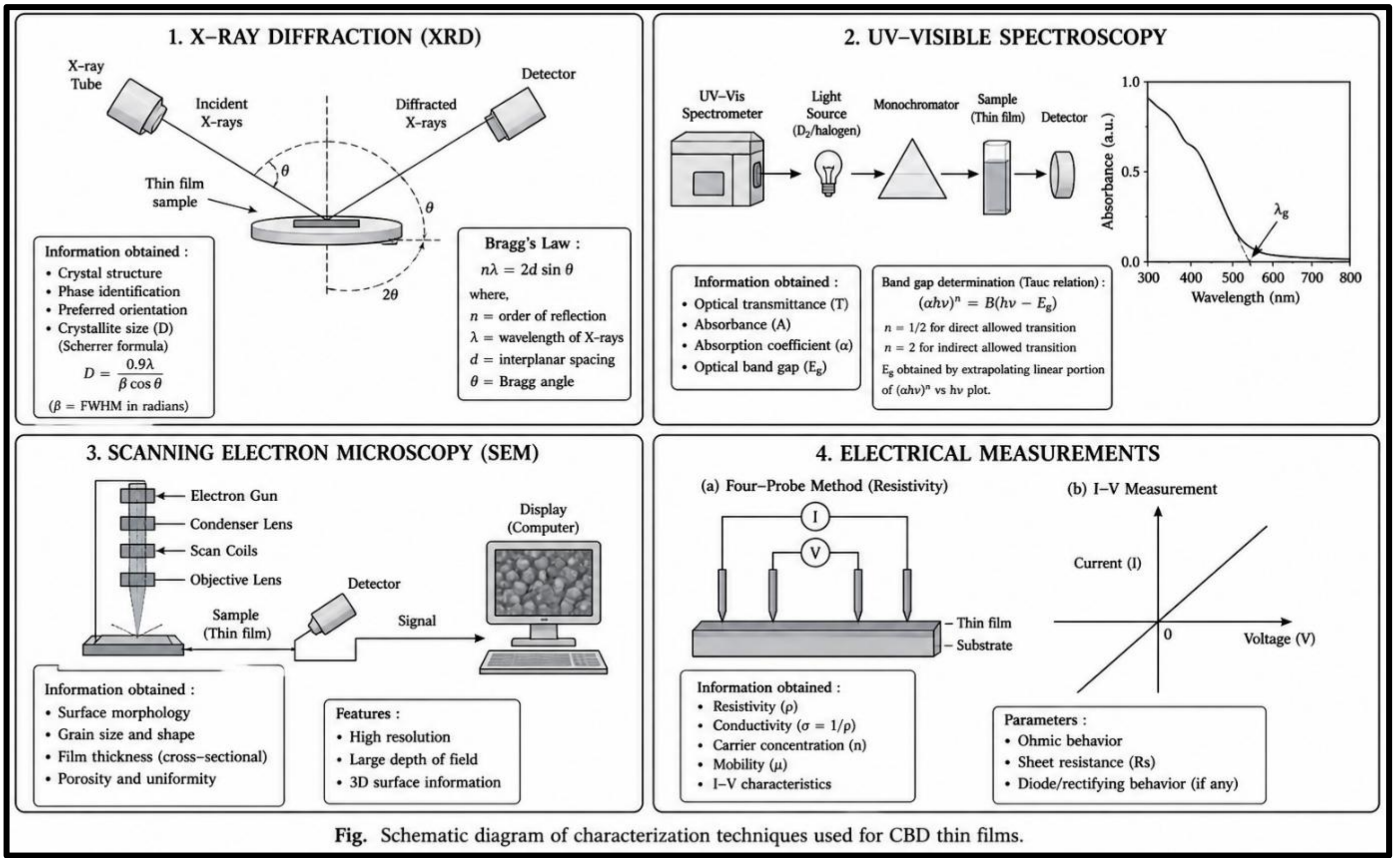


**Fig.** Schematic diagram of characterization techniques used for CBD thin films.

## 4. RESULTS AND DISCUSSION

The thin films deposited using the Chemical Bath Deposition (CBD) method were found to be uniform, well-adherent and free from visible defects on the substrate surface, indicating the effectiveness of the deposition process [28]. Proper cleaning of Substrates and controlled deposition parameters contributed significantly to achieving homogeneous film growth.

The X-ray Diffraction (XRD) analysis revealed distinct diffraction peaks corresponding to the crystalline phases of the deposited material, confirming the polycrystalline nature of the thin films [29]. The peaks were found to match well with standard JCPDS data, indicating phase purity. The crystallite size, calculated using the Scherrer equation, was observed to be in the nanometer range, which is suitable for optoelectronic applications [19]. It was also observed that an increase in deposition temperature led to sharper and more intense peaks, indicating improved crystallinity.

The surface morphology of the films was examined using Scanning Electron Microscopy (SEM). The SEM images showed uniform grain distribution with fine and densely packed grains, indicating good surface coverage [30]. The absence of cracks and pinholes suggests that the films possess good mechanical stability and adhesion properties. Grain size was found to increase slightly with increasing temperature, which supports enhanced crystal growth under higher thermal conditions [26].

The optical properties of the thin films were studied using UV-Visible spectroscopy. The absorption spectra indicated a strong. absorption in the visible region, making the films suitable for photovoltaic applications [31]. The optical band gap was determined using Tauc plots and was found to be within the expected range for semiconductor materials. A slight variation in band gap values was observed with changes in deposition parameters, which can be attributed to quantum confinement effects and variations in crystallite size [20].

The electrical properties of the films were analysed using standard measurement techniques. The results indicated moderate electrical conductivity, which is typical for CBD-grown thin films [32]. The conductivity was found to increase with annealing and doping due to improved charge carrier mobility and reduced defect density. These properties make the films suitable for applications in electronic and optoelectronic devices [21].

The influence of deposition parameters such as temperature, pH and deposition time was found to be significant in determining the overall quality of the thin films. Higher temperatures enhanced ion mobility and reaction kinetics, resulting in improved crystallinity and grain growth [33]. The pH of the solution played a crucial role in controlling the release of ions and the thickness of the film, where an optimum pH resulted in uniform and defect-free films [14]. Similarly, longer deposition time increased film thicknesses up to a saturation limit, beyond which no significant growth was observed due to depletion of reactants [22].

Overall, the results demonstrate that careful optimisation of CBD parameters leads to the formation of high-quality thin films with desirable structural, optical and electrical properties, suitable for advanced technological applications [17].

## 5. CONCLUSION

The present study successfully demonstrates the synthesis of thin films using the Chemical Bath Deposition (CBD) method, highlighting its simplicity, reliability and effectiveness as a solution-based deposition technique. The films deposited under optimised conditions were found to be uniform, well-adherent and of good quality, confirming the suitability of CBD for thin film fabrication.

Structural analysis using X-ray Diffraction confirmed the polycrystalline nature and phase purity of the films, while morphological studies using SEM revealed smooth surface morphology with fine-grain distribution. These characteristics indicate that the deposited films possess good crystallinity and surface uniformity, which are essential for device applications.

Optical characterisation showed that the films exhibit appropriate band gap values and strong absorption in the visible region, making them suitable for optoelectronic and photovoltaic applications. Electrical measurements further indicated moderate conductivity, which can be enhanced through doping and annealing processes.

The study also emphasised the importance of deposition parameters such as temperature, pH and time, which significantly influence the structural, optical and electrical properties of the films. Proper control of these parameters enables the fabrication of high-quality thin films tailored for specific applications.

Overall, the CBD method is confirmed as a cost-effective, scalable and efficient technique for the synthesis of semiconductor thin films, making it highly suitable for both laboratory research and industrial applications.

## 6. Future Scope

Although the CBD method has proven to be effective for thin film deposition, several areas offer scope for further research and development. One of the key directions is the incorporation of doping elements to enhance electrical conductivity and modify optical properties of the films for improved device performance [37].

Another promising area is the development of multilayer and heterostructure thin films, which can significantly improve efficiency in photovoltaic and optoelectronic devices by optimising charge transport and light absorption [38]. Additionally, the integration of CBD-grown thin films into solar cells, sensors and flexible electronic devices presents vast opportunities for practical applications.

Advanced characterisation techniques such as atomic force microscopy (AFM), photoluminescence (PL) and Hall effect measurements can be employed to gain deeper insights into the material properties and carrier dynamics. These studies will help in understanding the fundamental mechanisms governing film behaviour.

Furthermore, efforts can be directed toward scaling up the CBD process for industrial production, ensuring uniformity, reproducibility and cost-effectiveness on a large scale. The development of eco-friendly and non-toxic precursor materials is also an important consideration for sustainable manufacturing.

In conclusion, the CBD technique holds significant potential for future advancements in nanotechnology, renewable energy and electronic device fabrication, making it a promising area for continued research and innovation [38].

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**About Corresponding the author**

**Dr. Dipak Ashok Zope** is an Assistant Professor at Padm. Dr. V. B. Kolte College of Engineering. He is actively engaged in engineering education, academic research, and technical innovation. His areas of interest include advanced engineering practices, student development, and interdisciplinary research contributing to higher education and technological advancement in India.