

Original Article

Physical And Chemical Methods: A Review on the Analysis of Deposition Parameters of Thin Film Preparation Methods

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Abstract

Thin-film deposition is a fundamental fabrication process used to produce material layers with thicknesses ranging from a few nanometers to several micrometers. The selection of an appropriate deposition technique and optimization of processing parameters are essential for achieving the desired structural, optical, electrical, and mechanical properties of thin films. This review presents a comprehensive analysis of the major thin-film deposition methods, including thermal evaporation, electron-beam evaporation, molecular beam epitaxy (MBE), sputtering, chemical vapor deposition (CVD), the sol-gel method, and spray pyrolysis. The working principles, deposition conditions, advantages, limitations, and application areas of each technique are critically discussed. Nanostructured thin films have become indispensable in advanced technologies because of their tunable physical and chemical properties at the nanoscale. They are extensively utilized in microelectronic and optoelectronic devices, energy conversion and storage systems, sensors, biomedical devices, integrated circuits, semiconductor components, photovoltaic cells, protective and wear-resistant coatings, memory devices, and superconducting applications. A comparative evaluation of the reported deposition techniques indicates that processing parameters strongly influence the morphology, crystallinity, composition, and overall performance of thin films. Among the available fabrication routes, chemical deposition methods offer significant advantages in terms of cost-effectiveness, scalability, compositional control, and the production of high-quality thin films, making them particularly suitable for large-scale industrial and research applications.

Keywords: Thin films, Deposition conditions, Physical methods, Chemical methods, Spray pyrolysis, Electron beam evaporation, Chemical vapor deposition

Introduction:

The rapid advancement of nanotechnology has enabled the fabrication of materials with nanoscale dimensions and ultrathin thicknesses, resulting in unique optical, electrical, optoelectronic, dielectric, magnetic, and mechanical properties that differ significantly from those of their bulk counterparts. These developments have established thin-film science and coating technology as important areas within materials science due to their broad scientific and technological significance [1]. Thin films are defined as layers of material with thicknesses ranging from a few nanometers to several micrometers, and their properties can be tailored by controlling the deposition process and film structure. A familiar example of thin-film technology is the metallic coating deposited on the rear surface of a mirror, which provides the reflective interface responsible for image formation. The use of thin metallic coatings dates back to ancient civilizations. Historical evidence suggests that early Egyptian artisans employed ultrathin gold coatings for decorative purposes on monuments, tombs, and other artifacts during the Bronze Age. In modern materials research, thin-film characterization has become an essential tool for understanding the relationship between processing conditions, microstructure, and material properties [2]. Investigations of thin films have significantly contributed to the advancement of solid-state physics and chemistry by enabling the study of phenomena that arise from reduced dimensionality, surface and interface effects, and film morphology, thereby supporting the development of a wide range of electronic, optical, and functional materials [3].

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1.1 Parameters: The important physical and chemical parameters of the thin film can be listed in the following table 1:

Table 1: Physical and chemical parameters of the thin films

Thin films	
Category	Parameters
Electrical	Conductivity; Resistivity; Permittivity; Stability under bias; Dielectric constant; Dielectric strength; Dielectric loss; Radiation hardness; Polarization; migration.
Thermal	Thermal conductivity; Thermal fusion temperature; Coefficient of expansion; Stability; Volatility; vapor pressure.
Mechanical	Intrinsic, residual, and composite stress; Anisotropy; Density; Ductility; Fracture; Hardness.
Optical	Absorption; Birefringence; Dispersion; Refractive index; Spectral characteristics.
Magnetic	Coercive force; Permeability; Saturation flux density.
Chemical	Composition; Corrosion and erosion resistance; Carcinogenicity; Etch rate; Impurity barrier effectiveness; Reactivity with substrate and ambient; Thermodynamic stability; Toxicity.

plications: Thin films have been used in a wide variety of applications in a wide variety of fields. It can be summarized as shown in Figure 1:

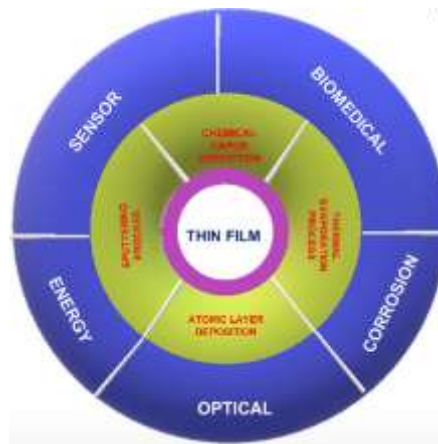


Fig 1: Applications of Thin Film Technology

2. **Classification of Thin-Film Deposition Techniques:** Nowadays, thin films can be made in a variety of ways. The deposition techniques can be divided into physical and chemical methods as described in Figure 2.

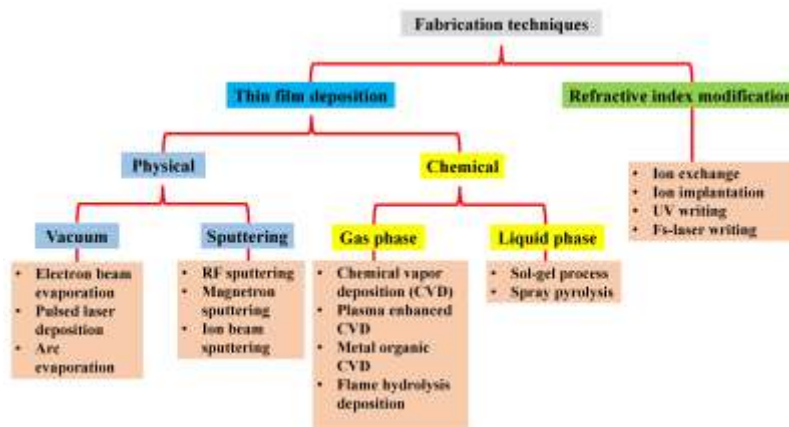


Fig. 2: Classifications of Thin-Film Deposition Techniques

1. Physical Deposition Methods (PDM):

There are many types of physical deposition methods, but in this review article, we focus on the some important PDM techniques.

2. Thermal evaporation: Thermal evaporation is one of the most widely employed physical vapor deposition (PVD) techniques for fabricating thin films. In this process, the source material is heated under high-vacuum conditions until it vaporizes. The generated vapor atoms or molecules travel through the vacuum with minimal collisions and condense onto the surface of a substrate, where they solidify to form a uniform thin-film coating. The vacuum environment helps minimize contamination and enables the deposition of high-purity films with controlled thickness and composition [4].

3. Electron beam (E-beam) evaporation: During electron-beam evaporation, the deposition chamber is typically maintained at a high vacuum of approximately 10^{-5} Torr or lower to minimize contamination and reduce collisions between vapor species and

residual gas molecules. The source material is generally supplied as an ingot or a compacted solid target. An electron beam, produced using electron guns based on thermionic emission, field emission, or anodic arc discharge, is accelerated to high velocities and precisely focused onto the source material. The impact of the high-energy electrons converts their kinetic energy into heat, causing localized melting and evaporation of the material. The resulting vapor then travels through the vacuum and condenses on the substrate surface, forming a thin film with controlled composition and thickness [5].

4. Molecular Beam Epitaxy: Molecular Beam Epitaxy (MBE) is an advanced thin-film deposition technique used for the controlled growth of high-quality epitaxial layers. In this process, thermally generated atomic or molecular beams are directed onto the atomically clean surface of a single-crystal substrate maintained at an elevated temperature under ultra-high vacuum (UHV) conditions. The vacuum level, typically below (10^{-10}) Torr, minimizes contamination and unwanted gas-phase interactions, enabling precise control over film composition, thickness, and crystal structure. Owing to these conditions, MBE is capable of producing epitaxial films with exceptional crystalline quality and high chemical purity, even at comparatively low substrate temperatures [6].

Arc Vapor Deposition: Arc vapor deposition is a physical vapor deposition (PVD) technique in which an electrical arc operating at high current and low voltage is used to vaporize either a cathodic or anodic electrode. The vaporized species become highly ionized within the plasma, and a negatively biased substrate is commonly employed to accelerate these ions toward its surface. The energetic ion bombardment enhances film adhesion, density, and overall coating performance. Because of these characteristics, arc vapor deposition is extensively applied for the fabrication of hard, wear-resistant, and decorative coatings in industrial applications [7].

5. Flash Evaporation: Flash evaporation is a deposition-related process that occurs when a liquid at an elevated temperature is suddenly exposed to an environment where the surrounding pressure is lower than its equilibrium saturation pressure. Under these conditions, a portion of the liquid undergoes rapid vaporization without requiring additional external heating. The phase transformation is driven by the pressure difference and involves the absorption of latent heat during the liquid-to-vapor transition. Owing to its rapid evaporation characteristics and efficient heat and mass transfer, flash evaporation has found widespread applications in seawater desalination, aerospace engineering, healthcare technologies, national defense, electronic manufacturing, and various industrial thermal processes [8].

6. Pulsed laser deposition (PLD): Pulsed laser deposition is a physical vapor deposition technique in which a high-energy laser pulse is focused onto the surface of a solid or liquid target, causing localized heating, ablation, and vaporization of a small quantity of material. The ablated plume consists of atoms, molecules, ions, electrons, and clusters, with its composition, energy distribution, and dynamics largely governed by the laser parameters, including pulse energy, wavelength, pulse duration, and intensity, as well as the properties of the target material. As the vapor plume expands toward a substrate, the ejected species condense and nucleate on its surface to form a thin-film layer. Continuous irradiation with successive laser pulses generates repeated ablation events, resulting in the gradual growth of the deposited film. Owing to its excellent control over film composition and stoichiometry, pulsed laser deposition is widely employed for the fabrication of high-quality thin films, particularly for complex oxide and multicomponent materials [9].

7. Sputtering and Magnetron Sputtering: Sputtering is a physical vapor deposition process in which energetic ions generated in a plasma environment bombard a target material, causing the ejection of atoms or molecules from the target surface. These sputtered species subsequently travel through the vapor phase and condense onto a substrate to form a thin-film coating. Conventional diode sputtering methods were initially limited by drawbacks such as low deposition efficiency and high operational costs, which restricted their widespread application. To overcome these limitations, a magnetically enhanced form of diode sputtering, known as magnetron sputtering, was introduced during the 1970s [10]. Magnetron sputtering utilizes a strategically arranged magnetic field near the target surface to confine electrons, increase plasma density, and enhance the sputtering efficiency. This improvement results in significantly higher deposition rates compared with conventional diode sputtering. The technique enables the fabrication of thin films from a wide range of materials, including metals, alloys, and ceramic compounds, on various substrate types, making it a widely adopted method for industrial and research-scale coating applications [11].

8. Radio frequency (RF) Sputtering: Radio frequency sputtering is an advanced form of sputtering technique primarily used for depositing thin films from insulating and conducting target materials. In this process, an alternating electrical potential is applied to the plasma system under vacuum conditions at radio frequency levels. The target material functions as the cathode, while the anode is positioned opposite to it and is electrically coupled through a blocking capacitor. This capacitor, together with an impedance-matching network, facilitates efficient power transfer from the RF generator to sustain the plasma discharge. During deposition, the cathode is subjected to a high-frequency voltage, commonly at 13.56 MHz, which generates energetic ions within the plasma. These accelerated ions strike the target surface and transfer sufficient energy to eject atoms from the target material. The sputtered atoms then migrate toward the substrate, where they condense and form a uniform thin-film coating. RF sputtering is widely used because it enables the deposition of high-quality films from a broad range of materials, including dielectric compounds [12].

9. Direct Current (DC) Sputtering: DC sputtering is a conventional physical vapor deposition technique that employs two parallel electrodes, consisting of a negatively biased cathode and a positively charged anode. The material intended for deposition is mounted on the cathode, which acts as the sputtering target, while the substrate is generally placed on the anode side. A low-pressure inert gas, most commonly argon, is introduced into the deposition chamber to generate and maintain the plasma discharge. Argon is preferred over lighter gases such as helium and neon because its higher atomic mass provides more effective momentum transfer during ion bombardment, while it remains more economical than heavier gases such as xenon and krypton. A DC potential difference applied between the cathode and anode accelerates positively charged gas ions toward the target surface. The impact of these energetic ions causes the ejection of target atoms through momentum transfer, and the released species subsequently travel through the plasma region before condensing on the substrate to form a thin-film coating. This method is widely used for depositing metallic and conductive thin films due to its simplicity and reliability [13].

10. Ion beam sputtering: In this deposition approach, a high-energy ion beam generated from an ion source is directed toward the target material, resulting in the ejection and subsequent deposition of target species onto the substrate to form a uniform thin

film. Since the deposition process is driven by ion bombardment rather than thermal evaporation, the deposition rate is largely independent of the vapor pressure of the target material. This technique enables the fabrication of highly pure thin films; however, it requires a high-vacuum environment, sophisticated equipment, and high-quality target materials, which increase the overall cost of the process [14]. This review summarizes several advanced and widely used physical deposition techniques for thin-film fabrication, along with their fundamental principles, benefits, limitations, and comparative features, as presented in Table 2.

Table 2: Advantages and disadvantages of PDM

Physical Deposition Methods (PDM) – Advantages and Disadvantages		
Deposition Methods	Advantages	Disadvantages
Thermal evaporation	High deposition rate; Simple and inexpensive equipment; Good quality films.	Very Poor coverage; Difficult deposition process; Needs substrate heating.
Electron beam evaporation	Multiple thin films, high-quality deposition; Clean growth process.	Non uniform evaporating rate; More expensive; Damage thin film surface.
Molecular beam epitaxy	High purity films, Produce epitaxial materials; Clean surface films.	Complicated and high-cost equipment; Low deposition rate; Needs vacuum.
Flash evaporation	Simple and better coatings; Good environment adaptability; High deposition rate.	Low efficient technique; Complicated process; High operating temperature.
Arc evaporation	All electrically conductive materials can be vaporized; Composition control; Removal of inclusions	Growth defects; Lower melt rate; High cost.
Pulsed laser deposition	Dense and porous coatings; Simple and precise process; Needed lower substrate temperature.	Very expensive; Defected substrate surface and growing film; Slow rate of deposition.
Magnetron sputtering	High adhesion; Uniform coating thickness; Low temperature process.	Very expensive method; Low deposition rate; Unstable plasma.
Radio frequency sputtering	Works well with insulating targets; Higher efficiency; Better film quality and step coverage.	Deposition rate is very low; Non uniform deposition; Expensive technique.
Direct current sputtering	Good Step coverage; Simple and good coating method; Low temperature technique.	Low sputtering rate; Slower deposition; Inefficient secondary electron process.
Ion beam sputter deposition	Uniform coating thickness; High quality and precision films; Thickness control and stability.	Low deposition rate, expensive method; complicated device

1. Chemical Deposition Methods (CDM):

A wide range of chemical deposition techniques have been developed for thin-film fabrication. However, this review primarily focuses on several significant and commonly employed chemical deposition methods, highlighting their principles, processing conditions, advantages, and limitations.

2. Chemical vapor deposition (CVD): Chemical vapor deposition (CVD) is a widely used thin-film fabrication technique in which gaseous precursors undergo chemical reactions or decomposition on the surface of a heated substrate, resulting in the formation of a solid film layer. The process involves one or more volatile compounds containing the desired film-forming elements, which react under controlled conditions to produce high-quality coatings. Due to its versatility and ability to deposit a wide range of materials, CVD is extensively employed in industrial applications for producing organic and inorganic thin films on metals, semiconductors, ceramics, and other substrate materials [15].

Depending on the operating pressure, energy source, and precursor chemistry, CVD processes can be categorized into several variants, including atmospheric-pressure chemical vapor deposition (APCVD), low-pressure chemical vapor deposition (LPCVD), ultrahigh-vacuum chemical vapor deposition (UHVCVD), plasma-enhanced chemical vapor deposition (PECVD), plasma-assisted chemical vapor deposition (PACVD), laser-enhanced chemical vapor deposition (LECVD), and metal-organic chemical vapor deposition (MOCVD). Each of these techniques offers specific advantages and is selected according to the required film properties, deposition rate, and application requirements.

3. Atomic layer deposition (ALD): Atomic layer deposition (ALD) is an advanced thin-film growth technique based on sequential, self-limiting surface reactions that enable precise control over film thickness at the atomic scale. In this process, two or more gaseous or vapor-phase precursors are introduced separately into the reaction chamber, where they react with the substrate surface in a controlled sequence to form a solid thin-film layer. The self-limiting nature of these surface reactions allows highly uniform and conformal coatings to be achieved, even on complex three-dimensional structures.

Most ALD systems operate using a flow-through reactor configuration, in which an inert carrier gas continuously transports precursor pulses through the deposition chamber. The precursor vapors are introduced as short, controlled pulses, and the carrier gas directs them through the reaction zone in a sequential manner. After surface reactions occur, excess reactants and by-products are removed through pumping and filtration systems before the next precursor pulse is introduced, allowing gradual and precise film growth [16].

4. Chemical Bath Deposition (CBD): Chemical bath deposition (CBD), also referred to as solution growth, controlled precipitation, or chemical deposition, is a solution-based thin-film fabrication technique that has gained significant attention for the preparation of metal chalcogenide films. This method can be considered the liquid-phase counterpart of chemical vapor deposition (CVD), where film formation occurs through chemical reactions in a solution rather than in the gas phase.

A major advantage of the CBD technique is its simplicity and cost-effectiveness compared with vacuum-based deposition methods. Unlike many conventional thin-film fabrication approaches, CBD does not require complex vacuum systems or expensive processing equipment. The deposition process can be carried out using relatively simple laboratory setups, such as a temperature-controlled hot plate equipped with a magnetic stirrer, making it suitable for large-area and economical thin-film production [17].

5. Sol - gel process: Sol-gel processing is a versatile and interdisciplinary technique that combines principles of chemistry, physics, and materials science for the synthesis of advanced materials. The term “sol-gel” represents the transformation of a liquid-phase sol into a solid gel structure. Among its various applications, the fabrication of thin films is one of the most significant due to the ability of this method to provide precise control over composition, structure, and morphology.

In the sol-gel process, a stable colloidal suspension known as a sol is initially formed through the hydrolysis and partial condensation of molecular precursors. These reactions promote the development of metal-oxygen-metal (M-O-M) linkages within the growing network. With continued condensation, the dispersed sol particles connect to form a three-dimensional inorganic gel structure. Subsequent removal of the trapped solvent from the gel results in the formation of porous or dense materials, such as xerogels and aerogels, depending on the drying conditions employed [18].

6. Spray pyrolysis (SP): Spray pyrolysis is a chemical deposition technique in which thin films are synthesized by spraying a precursor solution onto a heated substrate. When the fine droplets reach the elevated-temperature surface, solvent evaporation and thermal decomposition of the precursor occur, followed by chemical reactions that result in the formation of the desired thin-film material. The precursor compounds are selected carefully so that the by-products generated during the reaction remain volatile at the deposition temperature and can be easily eliminated from the film [19].

In this process, the precursor solution is transformed into microscopic droplets through atomization and transported toward the heated substrate with the assistance of a carrier gas. The interaction between the droplets and the hot surface promotes film formation through nucleation and growth processes. Spray pyrolysis offers several advantages, including the ability to coat large substrate areas, achieve good compositional uniformity, and produce homogeneous thin films with potential for scalable mass production [20].

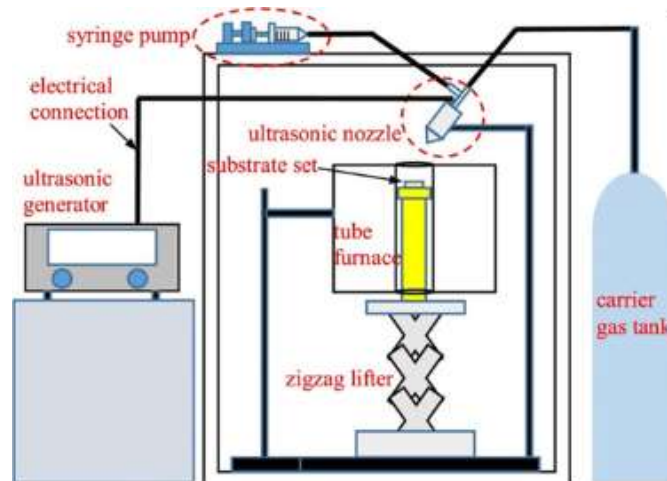


Fig. 3: The ultrasonic Spray Pyrolysis system

7. Successive Ionic Layer Adsorption and Reaction (SILAR): Successive Ionic Layer Adsorption and Reaction (SILAR) is a solution-based thin-film deposition technique that combines the principles of atomic layer deposition (ALD) and chemical bath deposition (CBD). The method relies on the sequential adsorption and reaction of ionic species on a substrate surface to achieve controlled film growth. Initially, one type of ion is adsorbed onto the substrate, followed by exposure to another ionic solution that reacts with the previously deposited species, resulting in the formation of an insoluble compound layer.

By repeating these adsorption and reaction cycles, the thickness of the deposited film can be gradually increased while maintaining control over the film composition and morphology. Due to its simplicity, low cost, and ability to deposit films on various substrates without requiring sophisticated equipment, SILAR has become an attractive method for thin-film fabrication [21].

8. Electrodeposition: Electrodeposition is an electrochemical thin-film fabrication technique in which a material layer is deposited onto an electrically conductive substrate from an electrolyte solution containing the corresponding ionic species. In this process, the substrate and a counter electrode are immersed in the electrolyte, and an external potential difference is applied between them to drive the reduction or oxidation reactions responsible for the formation of the deposited film on the substrate surface.

Depending on the direction of the applied potential and the nature of the electrochemical reaction, electrodeposition can occur through anodic or cathodic processes. In anodic deposition, the substrate acts as the positive electrode relative to the counter electrode, whereas in cathodic deposition, the substrate is maintained at a negative potential. The versatility, low processing cost, and ability to control film characteristics through electrochemical parameters make electrodeposition an important technique for thin-film synthesis [22].

9. Electroless deposition: Electroless deposition is a versatile chemical plating technique widely utilized for the fabrication of metallic coatings and the synthesis of various metal nanostructures. Unlike conventional electrodeposition methods, this process

does not require an external electrical power source. Instead, metal ions present in the solution undergo an autocatalytic chemical reduction reaction on the substrate surface, resulting in the formation of a metallic thin-film layer.

This technique, also known as electroless plating, is particularly effective for depositing noble metal films on a variety of substrate materials. Due to its simple operation, uniform coating capability, and potential for large-scale production, electroless deposition provides an economical and scalable alternative for metal coating applications compared with traditional plating methods [23,24].

10. Spin-coating technique: Spin coating is a widely used thin-film fabrication technique for producing highly uniform coatings with thicknesses ranging from the micrometer to nanometer scale. In this method, a liquid precursor or coating solution is deposited onto a substrate mounted on a rotating chuck. The rotational motion generates centrifugal forces that spread the solution radially across the substrate surface, while viscous forces and surface tension contribute to the formation of a smooth and uniform layer.

As the substrate continues to rotate, excess solution is expelled from the surface and the remaining solvent gradually evaporates, resulting in the formation of a thin solid film. The spin-coating process generally involves several sequential steps, including solution dispensing, acceleration of the substrate (spin-up), uniform spreading of the liquid layer, removal of excess material (spin-off), and solvent evaporation, which together determine the final film thickness and morphology [25].

This review summarizes several advanced and widely adopted chemical deposition techniques used for thin-film fabrication. The fundamental principles, major advantages, limitations, and comparative characteristics of these methods are presented in Table 3.

Table 3: Advantages and disadvantages of CDM

Chemical Deposition Methods (CDM) – Advantages and Disadvantages		
Deposition Methods	Advantages	Disadvantages
Chemical vapor deposition	High deposition rate; Thick and uniform coating films; High purity and good quality films; Good reproducibility.	Require very high temperature; Expensive and complicated equipment; Organic exhaust gas is hazardous.
Chemical bath deposition	Very simple and low-cost deposition; Different thickness films; Works at any temperature; Needs only substrate and solution container; Uniform and hard film deposition.	Wastage of solution after each deposition; Clean substrate is required.
Atomic layer deposition	Excellent adhesion and good quality films; Uniformity and step coverage; Low temperature processing.	Very high energy waste rare; Low deposition rate; Very high material waste rate.
Ion implantation Low	Low temperature process; Very past and highly controlled method; Improved oxidation performance.	High-cost equipment; Line of-sight process.
Sol gel	High quality and purity; Low temperature deposition; High adhesion strength; Simple and low-cost equipment.	Long processing time; High cost of raw materials; Used limited number of materials; Harmful organic solvents.
Spray pyrolysis	High growth rate; Open atmosphere process; Low-cost deposition technique; High-quality adherent films of uniform thickness.	Complicated process; Very low yield.
SILAR	Good film growth rate; Low cost and energy saving method; Does not need vacuum chamber; Low deposition temperature.	High working pressure needed; Requirement of sophisticated environment.
Electro deposition	High deposition rate; Cheaper deposition method; Very good adherence; Simple and past process.	Thickness limitation; Not suitable for large scale production; Used only for conductive surface.
Electroless deposition	Low substrate temperature; Low cost method; Good filling capability; Scalability of large areas.	Poor controllability and reproducibility; Low deposition rate; Require pretreatment.
Spin coating	Simple and easy method; Low cost and past technique; High uniformity.	Less material efficiency; Coating material wastage, difficulty with large area samples.

3. Result and discussion:

In this review, a comprehensive analysis of various thin-film fabrication techniques has been presented, including both physical and chemical deposition approaches. The fundamental principles, processing methods, advantages, and limitations associated with different deposition techniques have been systematically discussed. The overall findings and comparative information collected from this study are summarized in Table 4. Furthermore, the important deposition-related parameters and process conditions extracted from the reviewed methods are organized and presented in Table 5. These comparative summaries provide a better

understanding of the essential parameters involved in thin-film formation and assist in selecting suitable deposition techniques for specific applications.

Table 4: Parameter analysis of physical and chemical deposition method

Physical / Chemical deposition methods	Deposition Parameters								
	Cost	Quality of film	Deposition time	Deposition rate	Equipment design	Process	Process temperature	Safety	Film thickness
Thermal evaporation	High	Moderate	High	High	Simple	Slow	Low	High	Thin
Electron beam evaporation	High	Moderate	Low	High	Simple	Past	Low	High	Thin
Molecular beam epitaxy	High	Excellent	High	Low	Complicated	Slow	High	High	Thin
Flash evaporation	High	Excellent	Low	High	Simple	Past	High	High	Thin
Arc evaporation	High	Excellent	High	Low	Complicated	Slow	High	High	Thin
Pulsed laser deposition	High	Excellent	High	Low	Simple	Slow	Low	High	Thin
Magnetron sputtering	High	Excellent	High	Low	Simple	Slow	Low	High	Thin
Radio frequency sputtering	High	Excellent	High	Low	Simple	Slow	Low	High	Thin
Direct current sputtering	High	Excellent	High	Low	Simple	Slow	Low	High	Thin
Ion beam sputter deposition	High	Excellent	High	Low	Complicated	Past	Low	High	Thin
Chemical vapor deposition	High	Good	Low	High	Complicated	Past	High	Low	Thick
Chemical bath deposition	Low	Good	High	Low	Simple	Slow	Low	Low	Thick
Atomic layer deposition	High	Excellent	High	Low	Simple	Slow	Low	High	Thick
Ion implantation	Low	Excellent	Low	High	Simple	Past	Low	High	Thick
Sol gel	Low	Excellent	High	Low	Simple	Slow	Low	Low	Thick
Spray pyrolysis	Low	Excellent	Low	High	Simple	Slow	High	Low	Thick
SILAR	Low	Excellent	Low	High	Simple	Past	Low	Low	Thick
Electro deposition	Low	Excellent	Low	High	Simple	Past	High	Low	Thick
Electroless deposition	Low	Excellent	High	Low	Simple	Past	High	Low	Thick
Spin coating	Low	Excellent	Low	High	Simple	Past	High	High	Thick

Table 5: Parameter results of physical and chemical deposition methods

Parameters	Physical methods	Chemical methods
Cost	High	Low
Quality of film	Moderate / Excellent	Excellent
Deposition time	High	Low
Deposition rate	Low	High
Equipment design	Simple / Complicated	Simple
Deposition process	Slow	Past
Process Temperature	Low	High
Film Thickness	Thin	Thick
Safety	High	Low

The results obtained in the present review study are as follows:

(1) The various parameters of thin film deposition methods have been studied and summarized.

- Physical methods are more expensive compared to chemical methods.

- Chemical methods produce better quality films as compared to physical methods.
- Long term deposition is observed in physical methods as compared to chemical methods.
- Higher deposition rates are observed in chemical methods as compared to physical methods.
- Equipment design is simpler in chemical methods compared to physical methods.
- The deposition process is slower in physical methods compared to chemical methods.
- Lower process temperatures are observed in physical methods as compared to chemical methods.
- Thicker thin films are observed in chemical methods as compared to physical methods.
- Physical methods provide more protection as compared to chemical methods.

(2) From the results obtained so far, we can conclude that chemical methods provide high-quality thin films at low cost compared to physical methods.

4. Conclusion:

Thin-film technology is a rapidly advancing field of materials science with continuous developments driven by emerging applications in electronics, energy, and nanotechnology. This review provides a comprehensive overview of thin-film deposition techniques, which are broadly categorized into physical and chemical deposition methods. The operating principles, important processing parameters, characteristic features, applications, advantages, and limitations of the major techniques in both categories are systematically discussed.

A comparative evaluation of these approaches indicates that chemical deposition methods offer significant benefits for large-scale thin-film production due to their cost-effectiveness, simplicity, and reduced requirement for sophisticated instrumentation. Many chemical deposition techniques can be performed without expensive vacuum-based systems, making them accessible and widely adopted for the fabrication of high-quality thin films across various research and industrial applications.

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Conflicts of interest

The authors declare that there are no conflicts of interest regarding the publication of this paper

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