

Thin film is two dimensional in its macroscopic appearance as its thickness is negligibly small (of the order of few micrometers).

Generally, films of thickness more than a micron are considered as thick films. The two dimensional aspect of the thin film makes them altogether different from their bulk counter parts.

It is possible to prepare thin films with required properties and morphology for any specific application by proper selection of deposition process and optimizing the deposition parameters.

**DIFFERENCE BETWEEN THICK AND THIN FILMS**

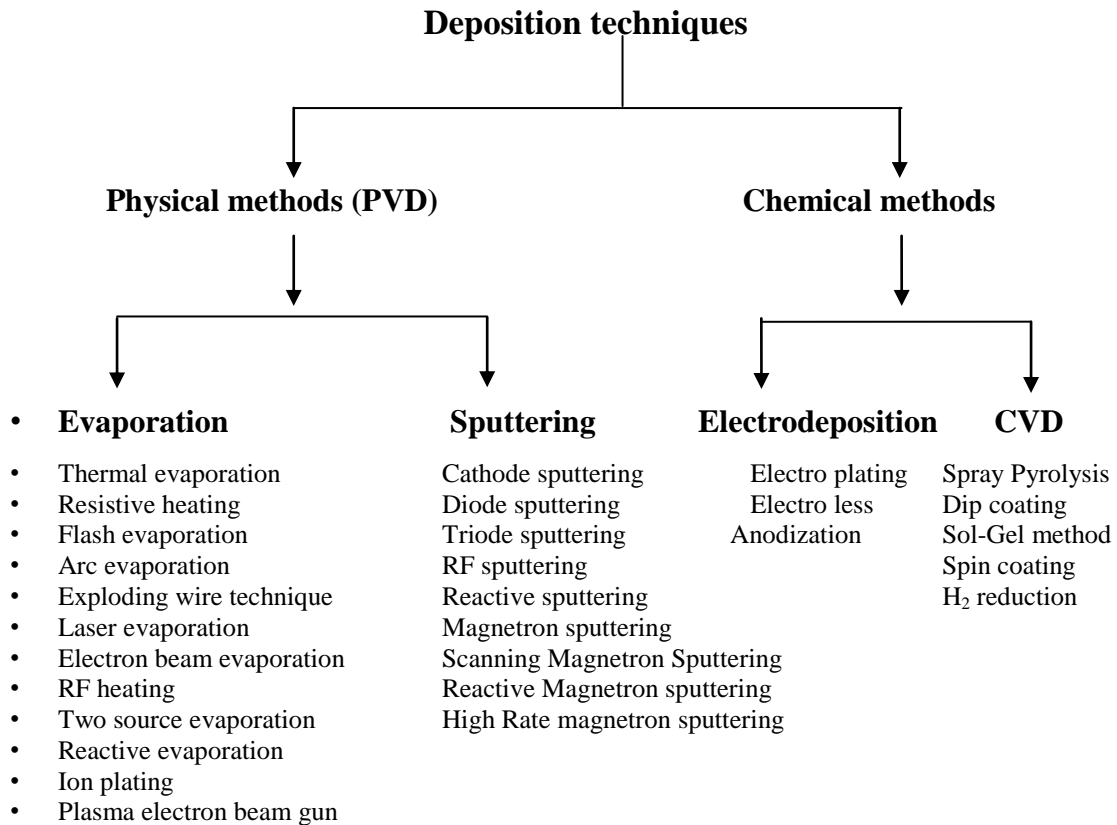
- Thin film may be arbitrarily defined as a solid layer having the thickness varying from a few Å to about 10 µm. categories are (i) Ultra thin (ii) thin (or very thin) (iii) comparatively thicker ones > 1000 Å.
- A thin film is two dimensional in its macroscopic appearance as its thickness is negligibly small (of the order of few nanometers). This two dimensional aspect makes it altogether different from its bulk counterpart.
- The characteristics of thin film mainly depend upon the environment and method of preparation of the sample. The films with reproducible results can be obtained by controlling various parameters involved in the process of deposition. Several methods have been adopted for the preparation of the thin films. Each one has got its own merits and limitations.

The different techniques of film formation can be broadly classified as:

- i) Physical Vapor Deposition (PVD)
- ii) Chemical Deposition (CD) and
- iii) Other techniques.

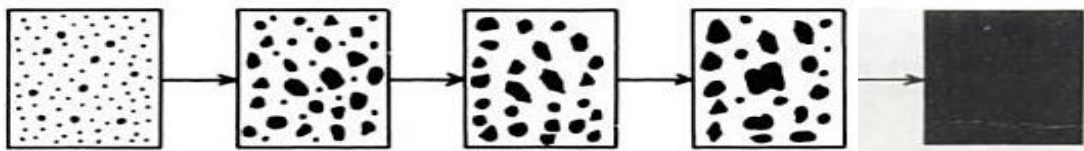
In physical vapor deposition, the film is formed by atoms directly transported from source to the substrate through phase. PVD techniques includes evaporation (thermal, E-beam), sputtering (Dc, Dc magnetron, RF) and reactive PVD.

In chemical vapor deposition the film is formed by chemical reaction on the surface of substrate. CVD techniques include low pressure CVD, Plasma enhanced CVD, Atmosphere pressure CVD and metal organic CVD.



### Stages of thin film growth

Nucleation  $\rightleftharpoons$  Condensation of vapors  $\rightarrow$  Adsorption of atoms  $\rightarrow$  Migration of atoms  $\rightarrow$  Formation of critical nuclei  $\rightarrow$  Stable clusters



Coalescence and agglomeration is the process of Collection of mass or cluster of materials.

Formation of small islands (addition of atoms), larger islands, gaps disappear and formation of continuous film.

## **CONDENSATION**

In the Vander-wall forces vapor atoms are initially interact with the surface of the atoms of the substrate, after they get physically absorbed, i.e atoms are loosely bound on the surface of the substrate the absorbed atoms are known as “ad-atoms”.

## **NUCLEATION**

The absorbed atoms (ad-atoms) movements on the surface of the substrate meet the other atoms and bound with them to form a cluster. The process continues then more and more atoms join the cluster due to the volume cohesion forces in the cluster.

The nucleation process yields three-dimensional randomly distributed Islands grown by further addition of new atoms from the vapor phase as well as by surface diffusion.

## **COALESCENCE FIRST STAGE**

On the surface of the substrate material, a large number of Islands are formed. As they come closer to each other, the larger ones appear to grow by coalescence or sintering of the smaller ones. Re-crystallization may take place during this sintering leading to crystallographic orientation changes. The method and nature of sintering or crystallization is dependent on deposition condition.

## **COALESCENCE SECOND STAGE**

In this case the Islands distribution begins at a definite time and reaches a critical stage as time proceeds. At this stage a rapid large-scale coalescence of the Islands result in a connected network structures and the Islands are flattened to increase the surface coverage. This process is very rapid in the beginning but slow down considerably on the formation of the network.

## **CONTINUOUS FILM**

This is the final stage of growth of thin film. In this process, to get uniform thin film filling the empty channels which require considerable amount of deposition. The above mentioned growth stages and the resulting patterns can be seen through by electron microscope technique in advanced thin film process.

Vapor deposited films generally contain a high density of lattice defects. Even in the most favorable cases of epitaxial films, it amounts to  $\sim 10^{11}$  dislocations per  $\text{cm}^2$ . The high density of defects and the presence of the free surface make it difficult to generate or move dislocations in a film. These defects play an important role in the electrical, mechanical, optical, dielectric and other properties of the films. For example, such a condition results in the enhancement of the tensile strength of films up to 2000 times the value in the corresponding bulk material. Thus thin film provides a medium for the study of the high yield strength and super plastic behavior of materials.

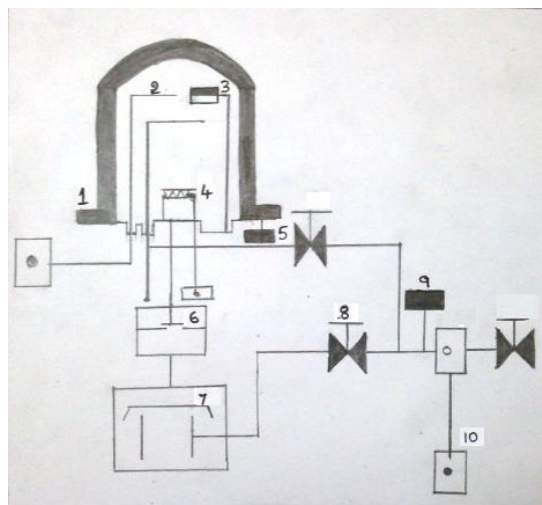
#### **Block diagram of a thin film unit**

A standard vacuum coating unit consists of a pumping system which comprises of a rotary vacuum pump, a diffusion pump and additional fully integrated and wired parts like valves, baffles, and gauges.



***Photograph of a vacuum coating unit.***

Photograph of the vacuum coating unit is shown in the figure above. A schematic diagram of a vacuum coating unit is shown in the figure below. A rotary pump (Pirani gauge to measure vacuum till  $10^{-3}$  Torr) along with a diffusion pump (a penning gauge to measure vacuum above  $10^{-3}$  Torr) is used to ensure clean and better vacuum of the range of  $10^{-6}$  Torr. Thus coating unit is fitted with a Pirani gauge used to measure the roughing vacuum and a Penning gauge to measure very high vacuum.



***Schematic diagram of vacuum coating unit.***

1. Bell jar 2. Crystal thickness monitor 3. Substrate holder 4. Filament with source material 5. Penning gauge 6. High vacuum valve 7. Diffusion pump 8. Backing valve 9. Pirani gauge 10. Rotary pump

Besides, inside the coating unit, substrates can be cleaned by an ion bombardment facility in partial vacuum. A low tension transformer of 10V-100A is used to heat the filament for resistive evaporation. Most of the evaporations are processed in a vacuum of about  $1-8 \times 10^{-6}$  Torr. Once the high vacuum is reached, resistive heating is done by heating the source (semiconductor or metallic) material with a resistively heated filament or boat (fill the boat or filament with the material to be coated), generally made of refractory metals such as W (tungsten) or Mo (molybdenum). Vapor sources of various types, geometrics and sizes can be easily constructed or obtained commercially. Some forms of these sources are basket, spiral, crucible heater dimple boat, etc. if a material has sufficiently high vapor pressure before melting occurs, it will sublime and the condensed vapors form a film.



***a. Boat***

***b. coils or filament***

On heating the source material in vacuum, it gets deposited onto the substrate (usually glass) for the required thickness, say 1000 Å and the film is kept in vacuum for few hours

for settling. Later the bell jar can be opened and the films can be used for various studies and characterizations.

## **THERMAL/VACCUUM EVAPORATION**

In this method, the material to be deposited is placed in a coil of filament or boat (source) which is heated resistively by passing the electric current and the vapor is allowed to condense on a clean substrate. As the current is passed through the heating element it gets heated and conducts heat to the evaporant. The material evaporates and gets deposited on the substrates. The sources that are commonly used are W, Mo SiO<sub>2</sub>. The process of evaporation has to be carried out inside the vacuum chamber. The nucleation and the film formation strongly depends on the thermal energy, rate of arrival and the incident angle of the vapor particles, as well as the physical, chemical and thermal conditions of receiving surface. In this method, the deposition is carried out essentially in a vacuum of magnitude where the mean free path of the ambient gas molecule is greater than the source to substrate distance. Theory of evaporation technique is based on the theory of vapor pressure, kinetic theory and thermodynamics.

## **SPIN COATING**

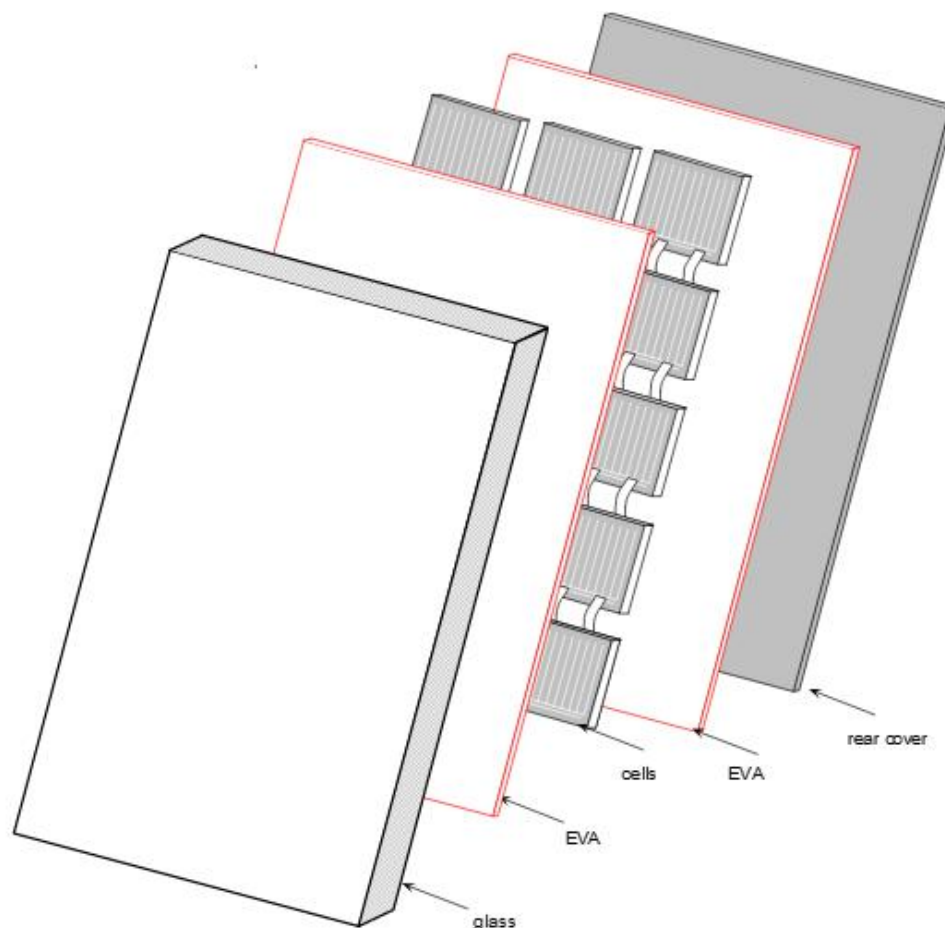
The process of applying a solution to a horizontal rotating disc, resulting in ejection and evaporation of the solvent and leaving liquid or solid film, is called **spin coating**. Spin coating is commonly employed for the highly reproducible fabrication of thin film coatings over large areas with high structural uniformity. Spin coating is a technique with which it is possible to apply a highly uniform film to a planar substrate over a large area with a highly controllable and reproducible film thickness. Spin coating is usually used for one side coating. In this, the substrate is placed on a spinner, rotated at about 200 rpm while solution is dripped on the center of the substrate. Films of thickness 50 to 500 nm are easily obtained in this method. Controlling the thickness is a matter of controlling the solution viscosity. Typical, solution viscosity are 3-10 poise, and the surface tension are  $30-50 \times 10^{-3}$  N/m. knowing the viscosity and oxide concentration of the solution, a film thickness can be achieved by controlling the spinning rate. Several broad areas such as Optical coatings, barrier coatings electronic coatings, protective coatings and abrasion coatings use spin coating techniques only. One of the first applications of spin coating was the application of paint coatings to various industrial products. The most widespread use of the spin-coating technique is for microelectronics applications .

The importance of spin coating is manifested in its widespread use in science and industry. The spin-coating technique applies to both in organic and inorganic/organic solution mixtures.

Spin coating is used in various applications such as coating of photo resist on silicon wafers, sensors, protective coatings, paint coatings, optical coatings and membranes. Silicon is patterned photo lithographically with a circuit design by coating semiconductor wafers with a polymeric photo resistant film that is subsequently exposed through masks to transfer the circuit design.

### **Silicon Based Solar Cell**

The majority of solar cells fabricated to date have been based on silicon in monocrystalline or large-grained polycrystalline form. There are two main reasons for this. One is that silicon is an elemental semiconductor with good stability and a well-balanced set of electronic, physical and chemical properties, the same set of strengths that have made silicon the preferred material for microelectronics. The second reason why silicon cells have been so dominant is that the success of silicon in microelectronics has created an enormous industry where the economies of scale directly benefit the presently smaller photovoltaics industry. Most silicon cells have been fabricated using thin wafers cut from large cylindrical monocrystalline ingots prepared by the exacting Czochralski (CZ) crystal growth process and doped to about one part per million with boron during ingot growth. A smaller but significant number use what are referred to as 'multicrystalline' wafers sliced from ingots prepared by a simpler casting (or, more generally, directional solidification) technique, which produces large-grained polycrystalline ingots. To produce a cell, these boron-doped starting wafers generally have phosphorus diffused at high temperatures a fraction of a micron into the surface to form the p-n junction required. Metal contacts to both the n - and the p -type side of the junction are formed by screen printing a metal paste that is then densified by firing at high temperature. Each cell is typically 10–15 cm either in diameter or along either side if square or rectangular.



*Figure 4.1* Exploded view of a standard silicon photovoltaic module. The different layers shown are laminated together under pressure at a temperature around 140–150 °C where the transparent EVA (ethylene vinyl acetate) softens and binds the different layers together on cooling. Source: Green and Hansen(1998).

Cells generally are sold interconnected and packaged into a weatherproof, glass- faced package known as a module, as shown in an exploded view in Fig. 4.1. Each module typically contains 36 cells soldered together in series. Since each individual cell gives a maximum output of about 0.6 V in sunlight, this results in a module of over 20 V maximum output voltage, sufficient for fully charging a normal 12 V lead- acid battery. The output current of each cell depends on its size and the sunlight intensity (solar irradiance) but generally would lie in the 2 – 5 A range in bright sunshine. The packaging consists of a glass/polymer laminate with the positive and negative leads from the series-connected cells brought out in a junction box attached to the module rear. Such modules have proved extremely reliable in the field with all manufacturers offering a 10 – 25 year warranty on the module power output, one of the longest warranties on any commercial



product (saucepans have been suggested as one of the few manufactured products with a comparable warranty period!).

The efficiency of the cells in the module would typically lie in the 12 – 16% range, less than half the fundamental ‘detailed-balance’ limit of 33% for silicon. Module efficiency is slightly lower than that of the constituent cells due to the area lost by frames and gaps between cells, with module efficiency generally lying in the 10 – 13% range. Over the last few years, commercial cells and modules of significantly higher performance have been available in multi-megawatt quantities using a more advanced cell processing technology (developed by the author’s research group). This technology produces cells of 17–18% efficiency and module efficiency in the 14 – 15% range. (Unless otherwise noted, all efficiencies quoted here are at standard test conditions, namely with a cell temperature of 25 C under 1000 W m<sup>-2</sup> sunlight intensity with the standard global air mass 1.5 spectral distribution).