

# Thin Film Deposition Processes

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## Abstract

During the last many decades the methods of forming thin films materials have increased significantly. In general, thin film is a small thickness that produces by physical vapour deposition (PVD) and chemical vapour deposition (CVD). Despite the PVD technique has a few drawbacks, it remains an important method and more beneficial than CVD technique for depositing thin films materials. This project examines some remarkable similarities and differences between PVD and CVD systems as well as evaluates the different techniques of depositing thin film. The majority of researchers have attempted to explain and justify the most precise system for depositing thin film since it is important in several applications such as surgical/medical and automotive. It is concluded that the most efficient method of depositing is PVD process. In addition, it has been found that there are more differences than similarities between PVD and CVD processes.

## Keywords

Thin Film, Physical Vapour Deposition (PVD), and Chemical Vapour Deposition (CVD)

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## 1. Introduction

Over the past approximately two centuries, there has been significantly changing thin film deposition process. Indeed, Fraunhofer first observed generating of thin film layer over 195 years ago on the surface of glass (ETAFILM Technology Inc, n.d). According to Wasa, Kitabatake and Adechi (2004), a thin film is a small-dimensional material on the substrate produced by intensifying, one-by-one, and ionic/molecular/atomic species of matter. The thickness of thin film is generally less than a number of microns. In fact, there is another type of film that is called thick film, which is known as a small-dimensional material formed by accumulating great grains/aggregates/clusters of ionic/molecular/atomic species or thinning a three-dimensional material.

Factually, over the past 50 years, the thin films have been used for manufacturing optical coatings, electronic devices, decorative parts, and instrument hard coatings. The thin film is a conventional well-established material technology. In

contrast, since the thin film technology is a main improvement of novel materials such as nanometre materials in the twenty-first century, it is still being developed on a daily basis (Wasa, Kitabatake and Adechi, 2004).

On the other hand, in the present time, the deposition process is classified into two types systems physical vapour deposition (PVD) and chemical vapour deposition (CVD), depending on the different principle causing film deposition. The first technique PVD is split into two classes thermal evaporation and sputtering; the second one CVD method is divided into plasma enhanced chemical vapour deposition (PECVD), laser chemical vapour deposition (LCVD), and metal organic chemical vapour deposition (MOCVD) (Singh and Shimakawa, 2003, and Pathan, 2004).

The aim of this project is to illustrate similarities and differences between two types of deposition process, which are physical vapour deposition (PVD) and chemical vapour deposition (CVD), for producing thin film material on the substrate. In addition, the purpose of this paper is to evaluate

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the most favourable methods of deposition process of thin film. Firstly, this project will not only provide a brief overview of physical vapour deposition and its types that are thermal evaporation and sputtering, but also explain advantages and disadvantages of PVD system in section one. Moreover, it will explain briefly only one method of the chemical vapour deposition, which is called plasma enhanced chemical vapour deposition (PECVD). Furthermore, the advantages and disadvantages of CVD system will then be examined in section two. Finally, will demonstrate compare and contrast the two processes in unit three.

## 2. Physical Vapour Deposition (PVD)

Freund (2003) claims that the physical vapour deposition, which is one of the approaches to fabricate thin film materials on the substrate, is a system that the physical processes occur through it such as evaporation, collision of ions or sublimation on a target, the transfer of atoms from a solid or molten source onto a substrate easily.

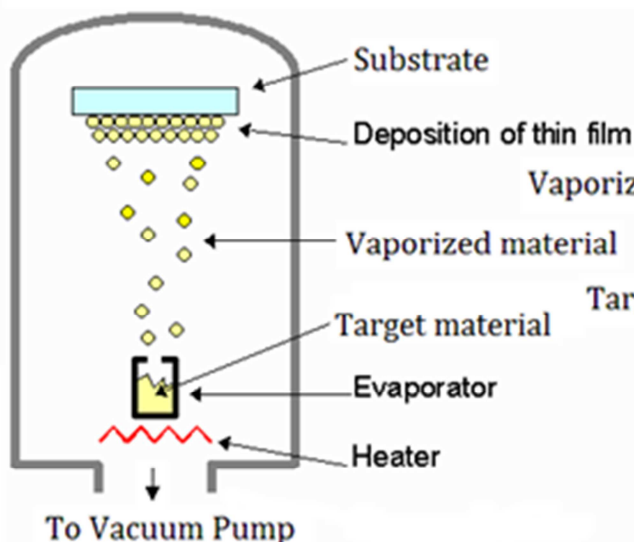
Generally, the PVD processes are performed under vacuum circumstances, and it is involved four steps. Firstly, evaporation, over this stage the target is evaporated by high energy source such as resistive heating or electrons beam.

Secondly, transportation, the vaporized atoms move from target to the surface of substrate through this phase. The third step is reaction, in some cases deposition, if there is a gas such as nitrogen or oxygen in the system, the atoms of materials reacts with the gas. If, however, in cases where the coating does not contain of gas, but it only consist of the target material, this phase does not be part of the process. Finally, deposition, through this stage the surface of substrate will be built. This technique is classified into two sorts, thermal evaporation and sputtering (AZoM 2002, and Korkin *et al* 2007).

### 2.1. Thermal Evaporation

Reference to Wasa, Kitabatake and Adechi (2004) reveal that the process of thermal evaporation, which is traditionally known as *vacuum deposition*, is used as a simplest technique for preparing thin film with a small number of micrometre ( $\mu\text{m}$ ) thicknesses. The thermal evaporation process consists of evaporating and condensing processes in a vacuum ( $\approx 1 \times 10^{-5}$  millibar) chamber. Firstly, source materials are evaporated by the heated source, which is maintaining a few cm distances from a substrate. Then, evaporated particles are condensed on the substrate. This process can use two types of sources that are resistive and electron beam source, which are shown in Figure (1).

#### Resistance heating evaporation



#### Electron beam evaporation

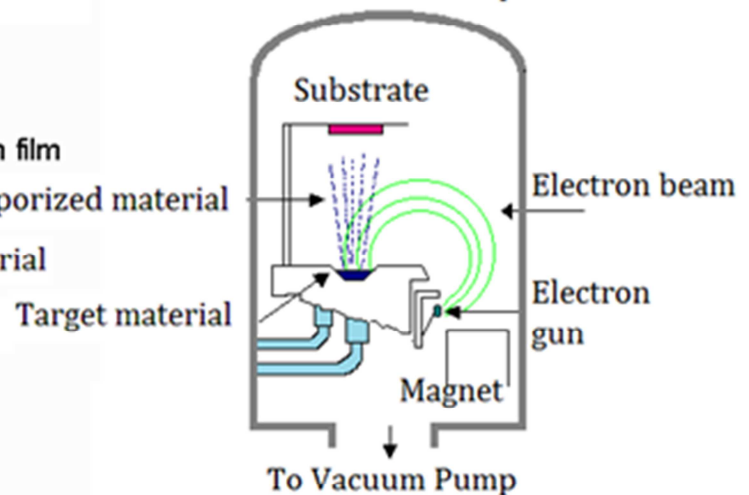


Figure (1). Types of thermal evaporation process.

The vacuum coating system shown in Figure (2) consists of mechanical rotary pump that is used to evacuate the chamber through the roughing line from atmospheric pressure to a level at, and diffusion pump which can be utilized as a primary pump to maintain the pressure in the chamber less than  $5 \times 10^{-2}$  millibar, and a high diffusion pump to conserve the pressure to

less than  $5 \times 10^{-5}$  millibar through the diffusion line (Chopra, 1969).

The resistive method consists of heating materials with a resistively heated boat or filament, usually manufactured of refractory metals such as tungsten, molybdenum and tantalum with or without ceramic coating (Chopra, 1969).

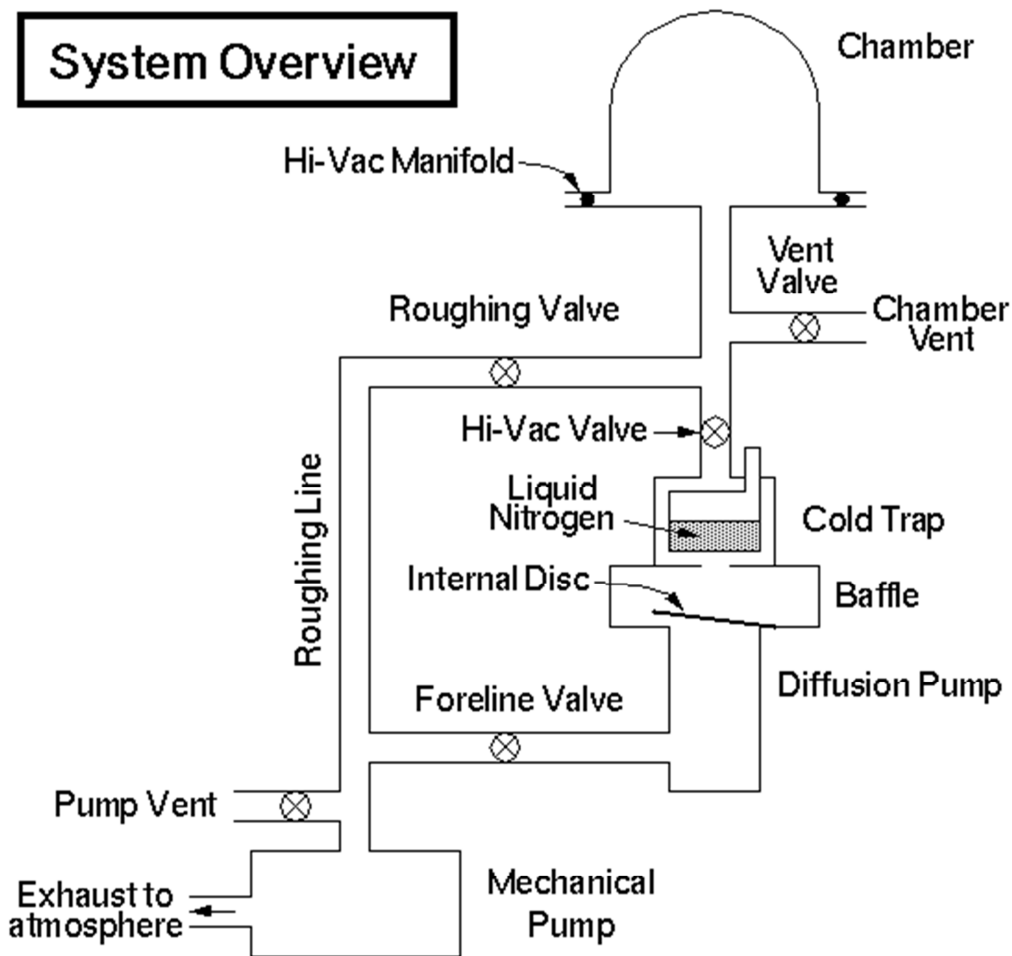


Figure (2). Schematic diagram of vacuum coating system.

There are several stages to forming thin film on the substrate. Firstly, loading the small amount of the coating material into the boat, which is in the chamber, and also putting substrate in the same chamber. Then, starting vacuum process for chamber in order to reduce pressure and leads path for the free atoms or molecules to very long mean free. After that pass high current (10-100A) during the boat that experiences resistive heating followed by vaporizing the depositing material thermally and the large vapour is able to reach to the substrate. Finally, it condensed back to the solid state, creating thin film (Cvimells Griot, n.d).

Chopra (1969) and Vossen (1991) observe that there are some problems related to the thermal evaporation. Changing properties of optical that results from impurities layers deposition, which is produced by reactions of some useful substances with the hot boat. As a result the stoichiometry of the material is strongly influenced by this method, and consequently the films formed that created by evaporation are not very practicable for optoelectronic applications. Moreover, Wasa, Kitabatake and Adechi (2004) and Freund (2003) report

that since the boat material (molybdenum, tungsten or tantalum) dissolves at a lower temperature, the resistive heating process cannot evaporate the materials that have high melting point, particularly metal oxides such as zirconia. If this process uses this material, the film on the surface will be impure. However, electronic beam (e-beam) heating removes these problems and has, thus, for deposition films vacuum evaporation technique become the favoured. In addition, kinetic energy of the atoms of the material is low in the thermal evaporation, and therefore, the deposition surface is protected from defect nucleation and damage.

## 2.2. Sputtering

Over 150 years ago, the first sputtering was observed in a discharge tube by Bunsen and Grove (Wasa, Kitabatake and Adechi, 2004). Sputtering is the second type of PVD process that uses active radiation kinds, which has several different systems that are used for thin-film deposition including dc diode (also known as dc sputtering and diode sputtering), radio frequency (rf) sputtering (called radio frequency diode), magnetron, and ion-beam sputtering. The simplest model

among these sputtering systems is the dc diode (Mattox, 2003 and Freund, 2003). Vossen (1991) points out that the atoms in the process of sputtering generally are evicted from surfaces of source commonly preserved at room temperature, during the influence of gaseous ions. It means that sputtering is the technology that is where the release of material from the source at a temperature much lower than the evaporation.

The system of dc diode is formed of vacuum chamber, power supply (high voltage), and two planar electrodes cathode and anode as shown in Figure (3). This system connects with the vacuum system to evacuate the chamber (Wasa, Kitabatake and Adechi, 2004, and Freund, 2003).

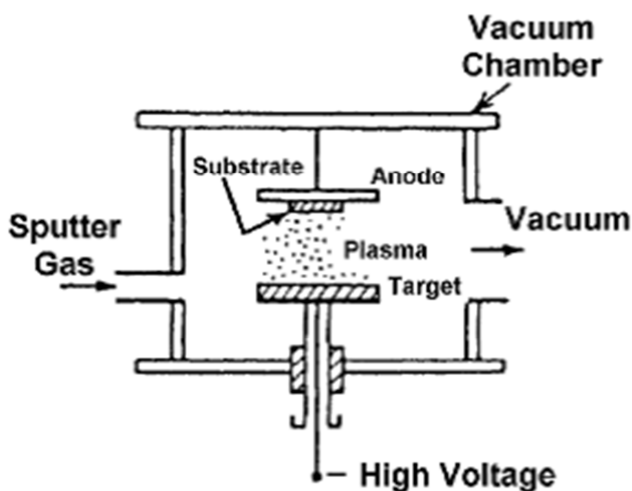


Figure (3). Dc diode system (Wasa, Kitabatake and Adechi, 2004: 40).

The source material, called target, is placed in the vacuum chamber on the cathode plate with the substrate locates on the anode plate, and fills with sputtering gas such as argon gas (Ar), which is an inert gas, at low pressure ( $4 \times 10^{-2}$  torr) (Wasa, Kitabatake and Adechi, 2004, and MEMSnet, n.d). In this type of system of deposition, ions of argon ( $\text{Ar}^+$ ) that produced in the radiance discharge are accelerated at high speed by an imposed electric field toward the cathode (target), and sputter the target, resulting in the thin films deposition on the substrates (Wasa, Kitabatake and Adechi, 2004, and Freund, 2003).

As Freund (2003) and SiliconFarEast (2004) point out, one of the main advantages of sputtering process is that control in preserving stoichiometry and regularity of film thickness is better than in evaporation process, and there is a flexibility of fundamental deposition of any amorphous and crystalline materials. Moreover, sputter deposition, for polycrystalline films, produces the film grain structure that has typically many crystallographic orientations without preferred texture. However, kinetic energy of sputtered atoms in sputter deposition is higher than that of atoms in the evaporative deposition because of the argon gas (Ar) existence in the

sputtering system. Therefore, the surface of deposition in sputtering process exhibits more damage and defect nucleation than in thermal evaporation. In addition, a concentration of impurity atoms of sputtered-deposited films is greater than thermal-deposited films. Furthermore, Grain size of the sputtered films is typically smaller than that of the films deposited by evaporation.

Based on the advantages and disadvantages of sputter and evaporation process, it can be seen that the thermal evaporation technique is more favourable than sputtering technique for depositing thin film for many materials that low and high melting materials, especially, metals.

### 2.3. Advantages and Disadvantages of PVD Process

Nothing is ever perfect; everything has negative and positive effects. It is undoubtedly true to say that although PVD process plays an important role in many fields, it has some obvious drawbacks. One of the significant advantages of using PVD process is that this process makes it possible for materials to deposit with developed properties compared to the substrate material. For instance, these techniques are commonly used to increase oxidation resistance, hardness and resistance of wear. As a result, it uses in a several of applications such as automotive, aerospace, surgical/medical, dies and shapes for all types of material processing, cutting tools and fire arms. Moreover, the PVD process enables approximately any type of inorganic material to use as well as certain categories of organic materials. In addition, it is environmentally approachable further than processes such as electroplating.

On the other hand, one of the important disadvantages is that the PVD technique requires appropriate cooling system for some processes operate at high vacuums and temperatures such as evaporate materials that has high melting point, and this system not only need skilled operators, but also demands high capital cost. In addition, frequently the rate of coating deposition is fairly slow; it is enormously difficult to coat similar surface and undercuts (AZoM, 2002).

In conclusion, it is important to note that even though there are some drawbacks associated with PVD process, particularly, slowing of rate of coating deposition and cost of existence of appropriate cooling systems, the benefits probably outweigh the disadvantages, especially as regards with increasing oxidation resistance, hardness and resistance of wear. As a consequence, the PVD is more preferable method than CVD, which will be focused in the next part, for depositing thin film for many materials as well as useful in wide range of applications such as automotive, aerospace and surgical/medical.

### 3. Chemical Vapour Deposition (CVD)

Choy (2003) reports that chemical vapour deposition is a technique whereby chemical processes such as chemical reaction at the substrate surface or in the surrounding of the substrate. According to Bhat (2006), in formal terms, CVD may be defined as a system in which a combination of gases reacts with the substrate surface at a relatively great temperature, leading to decay of certain of the constituents of the gas combination and the fabrication of a solid film of depositing of a metal or composite on the substrate. In fact, there are many sorts of CVD process, but this project is intending to explain only one significant of them, which is plasma enhanced chemical vapour deposition (PECVD).

#### 3.1. Plasma Enhanced Chemical Vapour Deposition (PECVD)

Plasma enhanced chemical vapour deposition (PECVD) is defined as a glow discharge chemical vapour deposition that is primarily utilized for the depositing of dielectric film and passivation films such as nitride or silicon oxide layers at low temperature. Electron energy (plasma) or heated gas introduces the necessary energy not only for the chemical reaction, but also to make it possible for coating to occur at a

low temperature and at a sensible rate (Pathan, 2004 and Choy, 2003).

In general, there are several steps in this technique to produce thin film as shown in Figure (2-1). Firstly, providing electrical power at an adequately great voltage to a gas at decreased pressures, consequences the avalanching of the gas then produces glow discharge plasma involving of ions, electrons and electronically excited species. Furthermore, electron affect ionize and dissociate the vapour reactants, and thus producing chemically energetic ions and radicals that undertake the heterogeneous chemical interaction at or close the heated substrate surface and coat the thin film. Although the temperature of the vapour reactants may continue close room temperature, the temperature of the electron can be approximately 20,000 K or higher, depending on the pressure at that the discharge is functioned (Choy, 2003 and Vossen, 1991).

Vossen (1991) also points out one of the significant advantages of PECVD system is that the deposition can occur on large areas at relatively low temperatures. In addition, it enables the microstructure deposition of film to be controlled separately. However, one of the main disadvantages of this process is that the film does not have high purity. Moreover, this technique is usually more expensive than other systems.

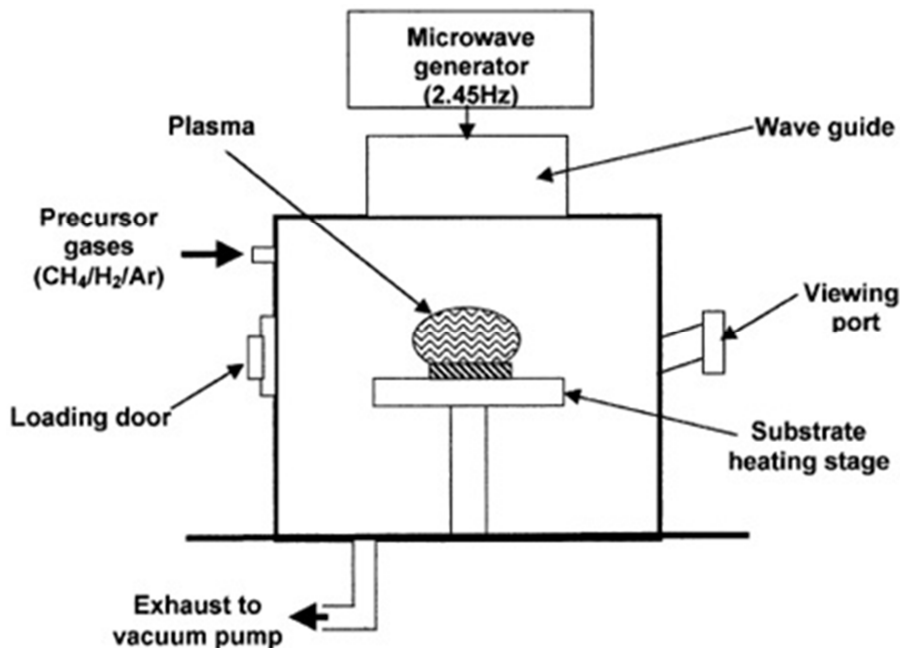


Figure (4). Plasma enhanced chemical vapour deposition (PECVD) (Choy, 2003: 113).

Based on the advantages and disadvantages of PECVD, it could be clearly seen that this method is more favourable than other CVD techniques for depositing thin film for many materials, particularly, dielectric films.

#### 3.2. Advantages and Disadvantages of CVD Process

The system of CVD as mentioned in introduction, it has positive and negative aspects. The main benefit of using this

system is that it can control structure of crystal and generate uniform films with pure materials and high density. Moreover, CVD system has ability to form film with good clone and adhesion at sensibly great deposition rates. However, this method cannot control stoichiometry of films using more than one material because different materials have different evaporation rates (Choy, 2003).

## 4. Compare and Contrast PVD and CVD Process

Pathan (2004), Choy (2003) and Freund (2003) found that there are several similarities and differences between Physical vapour deposition (PVD) and chemical vapour deposition (CVD) systems. Firstly, the system of vacuum of PVD and that of CVD are similar. They have vacuum chamber, rotary pump to produce low vacuum, and diffusion pump to acquire high vacuum. However, usually PVD process works under high vacuum, while CVD works under low vacuum.

Secondly, as far as temperature is concerned, the most remarkable similarity between PVD and CVD techniques is that the temperature of deposition in both systems is generally more than 150 °C. In contrast, PVD coating is deposited between 250°C and 450°C, whereas, CVD coating is deposited at high temperatures in the range of almost 450 C to roughly 1050°C.

Finally, in CVD, the material introduces in gaseous form onto the substrate, but it introduces in solid form in PVD. On the other hand, the gaseous molecules react with substrate in CVD, whereas the atoms are moving and depositing on the substrate in PVD.

Overall, it would appear that PVD and CVD systems are quite different in terms of temperature and degree of vacuum.

## 5. Conclusion

Over the last 195 years, the processes of depositing thin films materials have been considerably developing. Generally, there is not only physical vapour deposition system to produce thin film, but there is also chemical vapour deposition. In this project, several important aspects and techniques about thin film deposition process have been presented such as a brief overview of PVD process, types of PVD system that are thermal evaporation and sputtering, a brief overview of CVD process, PECVD that is a significant technique of CVD, and advantages and disadvantages of both systems. Finally, compare and contrast PVD and CVD have been discussed.

From explanation of thin film deposition processes that are PVD and CVD. It can be concluded that the thermal evaporation technique, particularly which has electron beam

source, is the most favourable methods for depositing thin film for materials that have high and low melting. By contrast, sputtering method is useful for depositing thin film for polycrystalline. On the other hand, for dielectric films the PECVD system is more beneficial than other CVD systems. Moreover, according to the many research, it can be seen that PVD is more favourable than CDV technique for fabricating thin film.

In discussion of compare and contrast PVD and CVD process, it was concluded that the main similarities between two processes are vacuum system and temperature of deposition. However, the level of vacuum and degree of temperature of each system are rather different. In contrast, the most remarkable difference is the form of introducing materials. For instance, the form of introducing material on to the substrate in PVD and CVD is solid and gaseous form, respectively. It would seem that PVD and CVD are slightly similar.

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