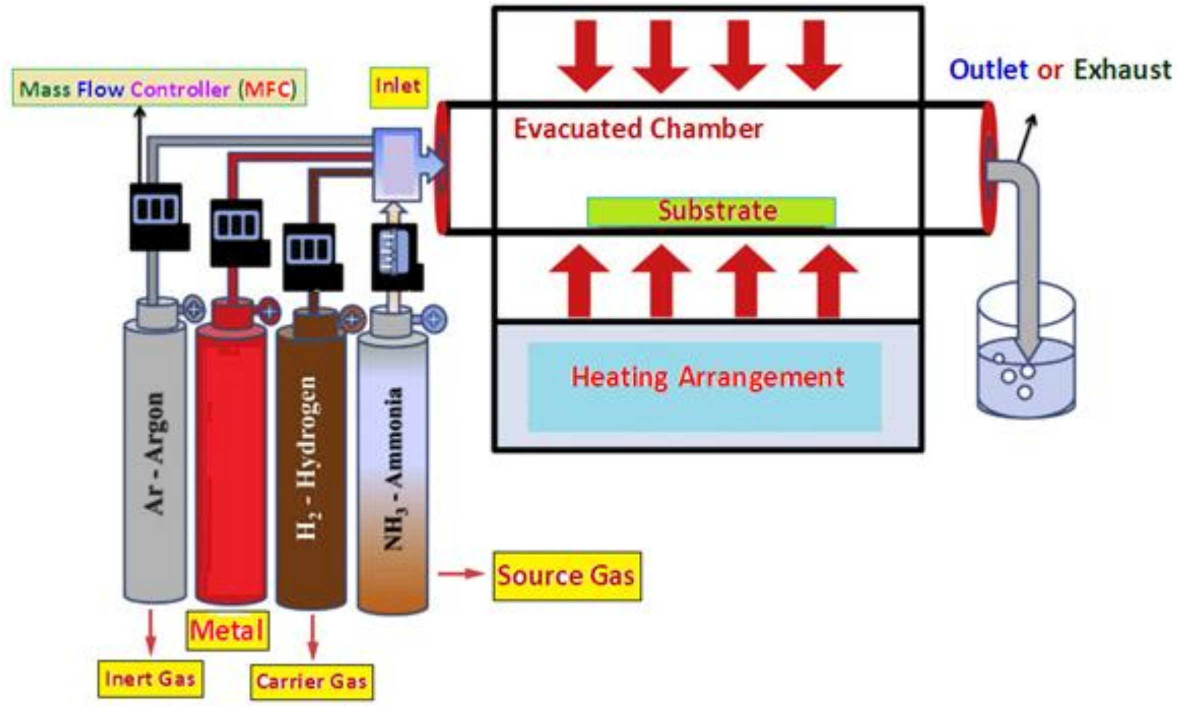
Vacuum Deposition:

Vacuum deposition which is also known as Vacuum evaporation is a general term of a typical surface treatment technology. The technology is used to deposit thin layers of nano materials onto a substrate (also called target surface). As the term suggests, vacuum deposition technologies must include the process that makes deposition of source (raw) materials in vapour state through condensation or chemical reaction or conversion in a vacuum environment.

When the vapour phase of source material is made deposited on target surface through a physical process like condensation then the process is called physical vapour deposition (PVD) and when it is made deposited on the substrate through chemical reaction made by vapour atoms or molecules with the substrate then the process is known as chemical vapour deposition (CVD). A schematic diagram of CVD is shown in figure.



After vaporization, atoms or molecules from the source material reach the target surface known as the substrate in a vacuum environment without colliding with residual gas molecules between the source and the substrate in the deposition chamber.

In order to avoid collisions, the mean free path of the molecules aiming the substrate should be very large which requires a vacuum better that 10 Torr inside the deposition chamber. At this pressure, there is still a large amount of concurrent impingement on the substrate by potentially undesirable residual gases that can contaminate the film deposited on the substrate. In such cases, a high (10 Torr) or ultrahigh (less than 1 Torr) vacuum environment is normally used to produce a film with the desired purity, depending on the deposition rate, reactivates of the residual gases and depositing species, and the tolerable impurity level in the deposit.

The advantages of this process of Vacuum Deposition for nano material synthesis are

a) It provides a low pressure plasma environment.

b) Here control of gas and vapour composition can be made

c) Here the mass flow can be controlled within the processing chamber.

Physical Vapour Deposition (PVD):

Here for Physical vapour deposition (PVD) it is a very popular vacuum deposition technique where a thin film of a source material is deposited over the entire substrate rather than in certain areas. The thickness of the deposited film can range from angstroms to millimetres. This particular technology is very versatile in nature and it can develop nearly homogeneous thin film of almost every type of inorganic materials such as metal, alloys, compounds and organic materials as well.

Over the past few years the application of PVD technologies has been increased tremendously in different important sectors of science and technology namely engineering, chemical, and nuclear, microelectronics and related industries. Since modern technologies demand multiple and conflicting set of properties materials which a single material cannot fulfil. So the only solution is therefore a composite material i.e. a core material along with a coating each having requisite properties to fulfil the requirements.

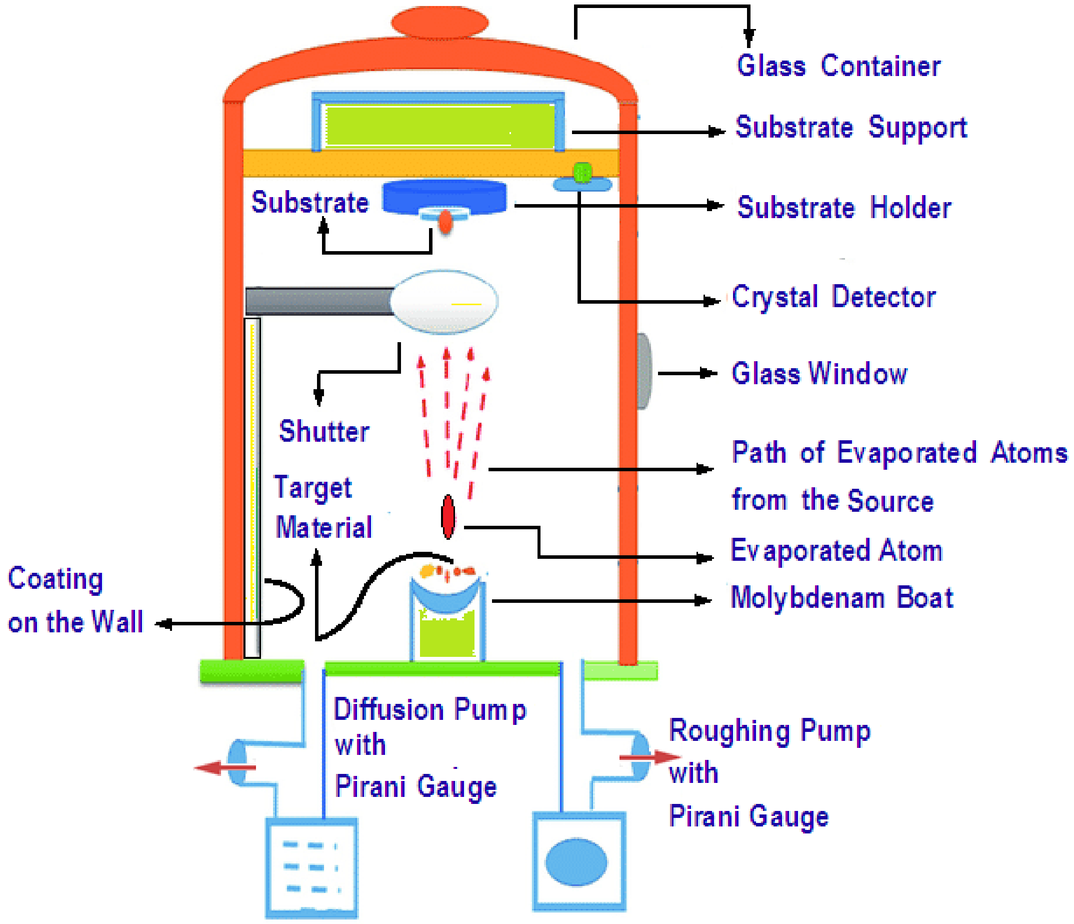
The primary objective of this type of deposition process is to transfer atoms from a source material to the substrate in a controllable manner. In this process, whatever be the source material inorganic or organic, it must remain in solid or liquid state such that it can vaporize from a condensed phase and then back to a thin film condensed phase.

Several methods are used to evaporate atoms from the source material and depending on that PVD variants differ from each other. For example, in thermal evaporation vaporization of source material is done through resistive heating, whereas in sputtering the same is done via bombarding the source material with a plasma (accelerated gaseous ions) or in electron beam evaporation the bombardment is done by electrons, in pulsed laser deposition (PLD) method a high intensity laser ablates material from the source into a vapour state.

The several types of PVD processes are thermal evaporation, e beam evaporation, pulsed laser deposition, arc vapour deposition, ion plating etc. A few of them will be discussed here.

a) Thermal Evaporation:

Thermal evaporation is the simplest and first practical PVD technique for the synthesis of nano materials. It is normally used for the synthesis of a variety of oxide and non oxide thin films. The solid source material is evaporated through resistance heating and then thin layer of atoms are deposited on a substrate via condensation.



The substrate on which the thin film is to be deposited is positioned facing the source. The pressure inside the vacuum chamber should be such that the mean free path of the evaporated atoms has the mean free path larger than the distance between the source and the substrate. A crystal monitor placed near the substrate records the quantity and rate of deposition. Normally the deposition rate in his particular PVD variant is few Atoms per seconds. Though this process is applicable for thin film preparation in photo voltaic, anti reflection coating in silicon based solar cells but requirement of high temperature $(1000\ \text{to}\ 1200^{\circ}\mathrm{C})$ and ultra high vacuum $(10^{-6}\ \mathrm{Torr})$ are the prime limitations of this process.

Here the advantages of this process of Thermal evaporation are

a) It is a simplest process and economically profitable

b) In this process of vacuum evaporation, solid material of any shape can be taken as source material.
c) Rate of deposition is high in this process

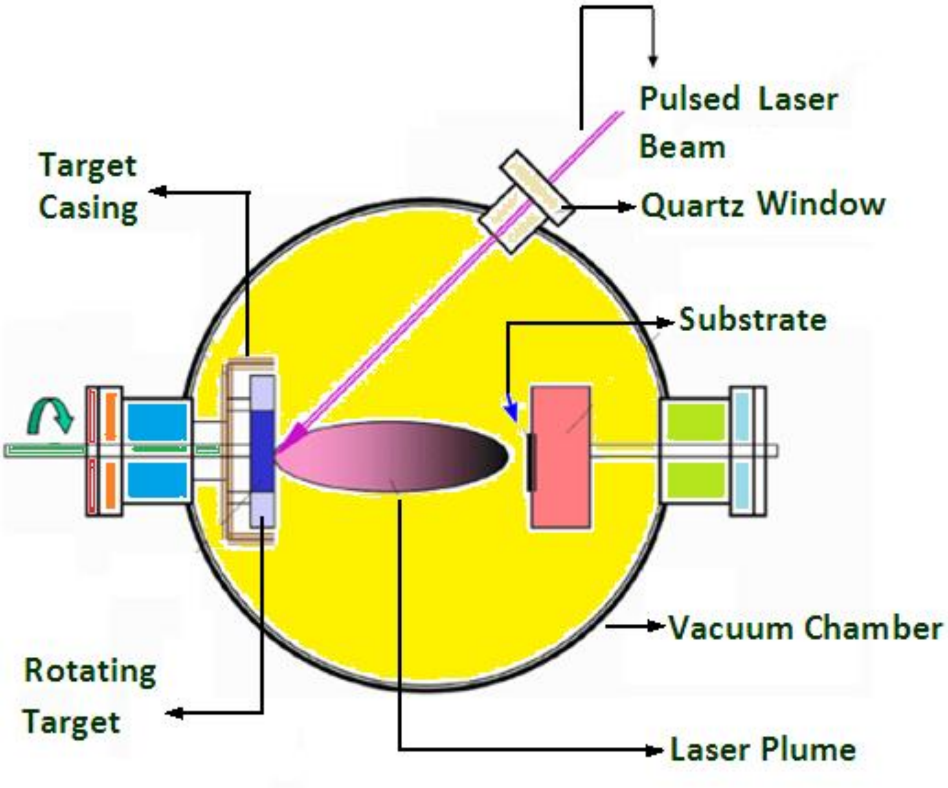
b) Electron Beam Evaporation:

Electron beam (E-beam) evaporation is a form of Physical vapour deposition technique. In this technique, the target material to be used as a coating is bombarded with an electron beam from a charged tungsten filament to evaporate and convert it to a gaseous state for deposition on the material to be coated.

The whole process takes place in a high vacuum chamber inside which atoms or molecules are in a vapour phase. Then these atoms or molecules precipitate a form a thin film coating or the substrate. Together with sputtering, E-Beam evaporation is the most common types or physical vapour deposition (PVD). Of these two processes, the E-Beam deposition technique has several clear advantages for many types of applications.

c) Pulsed Laser Deposition:

Pulsed laser deposition (PLD) is a physical vapour deposition technique where a high power pulsed laser beam is focused to strike a target of the desired composition. Material is then vaporized and deposited as a thin film on a substrate facing the target. This process can occur in ultra high vacuum or in the presence of a background gas, such as oxygen when depositing films of oxides.



Pulsed laser deposition (PLD) is a physical vapour deposition process that has been used for producing high quality films of material over the past few decades. It is a prime method for producing metal oxide based (MOX) gas sensing layers. The technique attracts scientific importance when a research group deposited a fine quality thin films of yttrium based cupric oxide (YBCO)-a high temperature superconductor around 1987.

Principle of operation: The technique uses high power laser pulses (typically$\sim 10^{8}\ \mathrm{W\,cm^{-2}}$) to melt, evaporate and ionize material from the surface of a target material. Entire process occurs inside a high vacuum chamber which may contain an inert gas such as argon or neon. Sometimes a background gas such as oxygen may also be present inside the chamber which provides a reactive atmosphere inside it. The vaporized or ablated material, containing neutrals, ions, electrons etc., is known as a laser-produced plasma plume and expands rapidly away from the target surface. The ablated material is then collected on an appropriately placed substrate upon which it condenses and the thin film grows.

In practice, the situation is not so simple, with a large number of variables affecting the properties of the film, such as laser fluency, background gas substrate temperature, roughness of the substrate surface, ionization density of the ablated material etc. These variables manipulate the film properties to some extent. However, optimization can require a considerable amount of time and effort. Indeed, much of the early research into PLD concentrated on the empirical optimization of deposition conditions for individual materials and applications, without attempting to understand the processes occurring as the material is transported from target to substrate. Generally femto second lasers $(10^{-15}\mathrm{s})$ lasers are used to deposit thin film having little nano meter thickness. A schematic diagram of pulse laser deposition machine is shown in figure.

Thus in Pulsed laser deposition, the following steps are taken for the formation of the thin film with thickness in nano range

i) The energy of the laser source is made absorbed by the surface of the target.

ii) By the help of laser therapy on the target material, plasma sheet (thin) is made.

iii) The thin plasma sheet is then transported from the target to the surrounding of the substrate

iv) Substrate is then cooled by flowing water.

v) The residual material is then deposited on the surface of the substrate.

vi) Nucleation i.e. the initial construction and then growth of the film is made on the surface of the substrate.