Thin Film Deposition

Thin Film Deposition can be achieved through two methods: Physical Vapour Deposition (PVD) or Chemical Vapour Deposition (CVD)

Physical Vapor Deposition (PVD) comprises a group of surface coating technologies used for decorative coating, tool coating, and other equipment coating applications. It is fundamentally a vaporization coating process in which the basic mechanism is an atom by atom transfer of material from the solid phase to the vapor phase and back to the solid phase, gradually building a film on the surface to be coated. In the case of reactive deposition, the depositing material reacts with a gaseous environment of co-deposited material to form a film of compound material, such as a nitride, oxide, carbide or carbonitride.

Physical evaporation is one of the oldest methods of depositing metal films. Aluminum, gold and other metals are heated to the point of vaporization, and then evaporate to form to a thin film covering the surface of the substrate. All film deposition takes place under vacuum or very carefully controlled atmosphere.

The degrees of vacuum and units is shown below:

Rough vacuum 1 bar to 1 mbar

High vacuum 10^{-3} to 10^{-6} mbar

Very high vacuum 10^{-6} to 10^{-9} mbar

Ultra-high vacuum < 10^{-9} mbar = vacuum in space

1 atm = 760 mm = 760 torr = 760 mm Hg = 1000 mbar= 14.7 p.s.i

1 torr = 1,33 mbar

Pressure (mbar)	Mean free path (λ: cm)	Number Impingement Rate (ϕ: $s^{-1} cm^{-2}$)	Monolayer impingement rate (s^{-1})
10^{-1}	0,5	$3\ 10^{18}$	4000
10^{-4}	50	$3\ 10^{16}$	40
10^{-5}	500	$3\ 10^{15}$	4
10^{-7}	$5\ 10^{4}$	$3\ 10^{13}$	$4\ 10^{-2}$
10^{-9}	$5\ 10^{6}$	$3\ 10^{11}$	$4\ 10^{-4}$

- the mean free path: $\boldsymbol{\lambda = kT/(\sqrt{2})\pi p d^2}$ **d** is the diameter of the gas molecule
- The rate of formation of a surface layer is determined by the impinging molecules:

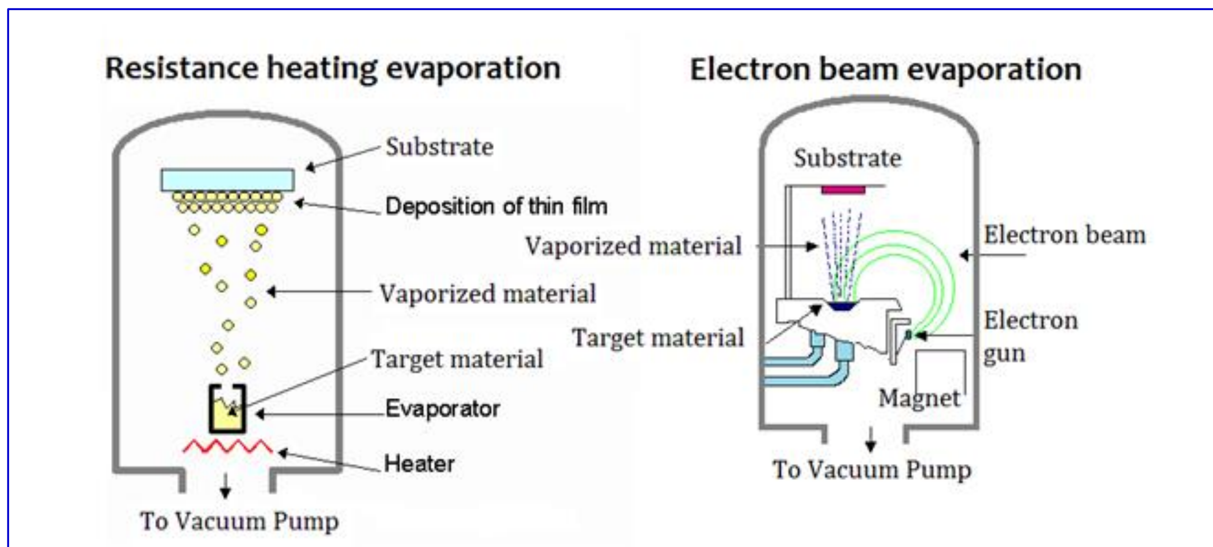
  $\boldsymbol{\phi = P/(2\phi\ mkT)^{1/2}}$ (molecules/cm^2 sec) where **m** is the mass of the molecule

VACUUM THERMAL EVAPORATION

Vacuum evaporation is also known as vacuum deposition and this is the process where the material used for coating is thermally vaporized and then proceeds by potential differences to the substrate with little or no collisions with gas molecules. Normal vacuum levels are in the medium to high vacuum range of 10^{-5} to 10^{-9} mbar.

In thermal evaporation techniques, different methods can be applied to heat the material. The equipments available in the laboratory use either resistance heating or bombardment with a high energy electron beam, usually several KeV, from an electron beam gun (electron beam heating)

In the ***Resistance heating technique***, the material is heated until fusion by means of an electrical current passing through a filament or metal plate (Evaporator) where the target material is deposited. The evaporated material is then condensed on the substrate. Other ways of heating are used, such as a RF coil surrounding a graphite or BN crucible, where the material to be evaporated is fused. The assembly of the technique is simple and results appropriate for depositing metals and some compounds with low melting temperature.



The ***Electron beam heating technique*** is based in the heat produced by high energy electron beam bombardment on the material to be deposited. The electron beam is generated by an electron gun, which uses the thermionic emission of electrons produced by an incandescent filament. Emitted electrons are accelerated by a high voltage potential (kilovolts). A magnetic field is often applied to bend the electron trajectory, allowing the electron gun to be positioned below the evaporation line. As electrons can be focalized, it is possible to obtain localized heating on the material to evaporate, with a high density of evaporation power. This allows controlling the evaporation rate, from low to very high values, and best of all, the chance of depositing materials with high melting point (W, Ta, C, etc.).

Advantages of vacuum evaporation:

- High-purity films can be deposited from high-purity source material.
- Source of material to be vaporized may be a solid in any form and purity.

- The line-of-sight trajectory and "limited-area sources" allow the use of masks to define areas of deposition on the substrate and shutters between the source and substrate to prevent deposition when not desired.
- Deposition rate monitoring and control are relatively easy.
- It is the least expensive of the PVD processes.

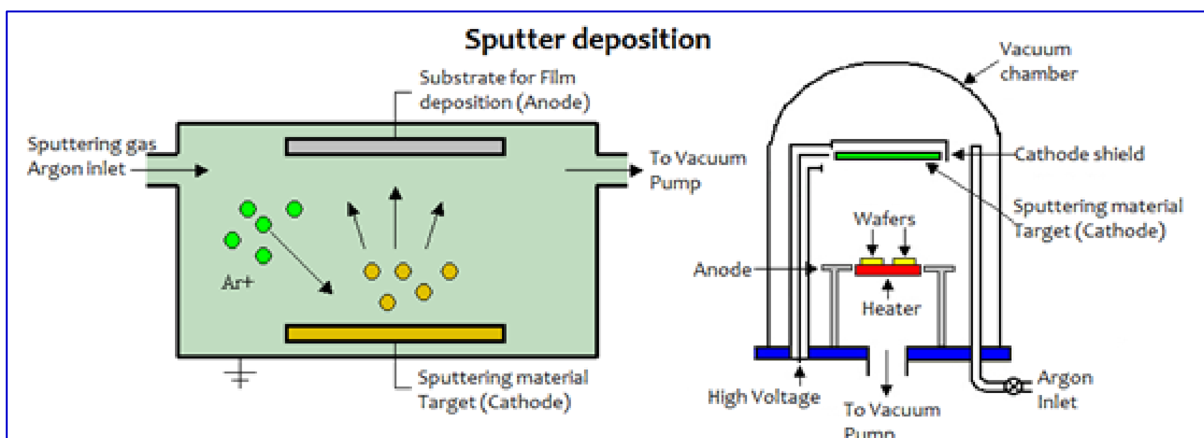
Disadvantages of vacuum evaporation:

- Many compounds and alloy compositions can only be deposited with difficulty.
- Line-of-sight and limited-area sources result in poor surface coverage on complex surfaces unless there is proper fixturing and movement.
- Few processing variables are available for film property control.
- Source material use may be low.
- Large-volume vacuum chambers are generally required to keep an appreciable distance between the hot source and the substrate.

Vacuum evaporation is used to form optical interference coatings using high and low index of refraction materials, mirror coatings, decorative coatings, permeation barrier films on flexible packaging materials, electrically conducting films and corrosion protective coatings.

SPUTTER DEPOSITION

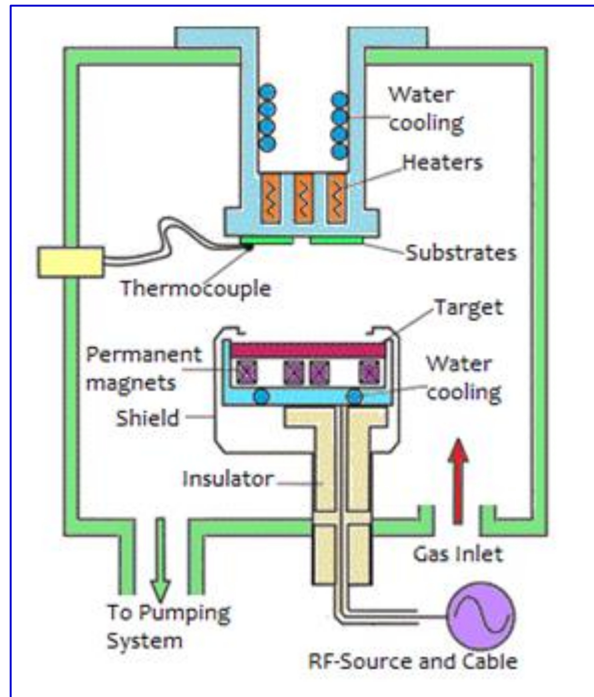
Sputter deposition are methods of depositing thin films by sputtering. They involve ejecting material from a “target” that is a source onto a “substrate” such as a silicon wafer. Sputtered atoms ejected from the target have a wide energy distribution, typically up to tens of eV. The sputtered ions (typically only a small fraction — order 1% — of the ejected particles are ionized) can ballistically fly from the target in straight lines and impact energetically on the substrates. The sputtering gas is often an inert gas such as argon. For efficient momentum transfer, the atomic weight of the sputtering gas should be close to the atomic weight of the target, so for sputtering light elements neon is preferable, while for



heavy elements krypton or xenon are used. he compound can be formed on the target surface, in-flight or on the substrate depending on the process parameters.

Magnetron sputtering is the most commonly used method for a sputter deposition. It usually utilizes a strong electric and magnetic fields to trap electrons close to the surface of the magnetron, which is known as the target. The electrons follow helical paths around the magnetic field lines undergoing more ionizing collisions with gaseous neutrals near the target surface than would otherwise occur.

The extra argon ions created as a result of these collisions leads to a higher deposition rate. It also means that the plasma can be sustained at a lower pressure. The sputtered atoms are neutrally charged and so are unaffected by the magnetic trap.



Advantages of sputter deposition:

- Elements, alloys and compounds can be sputtered and deposited.
- The sputtering target provides a stable, long-lived vaporization source.
- In some configurations, the sputtering source can be a defined shape such as a line or the surface of a rod or cylinder.
- In some configurations, reactive deposition can be easily accomplished using reactive gaseous species that are activated in plasma.
- There is very little radiant heat in the deposition process.
- The source and substrate can be spaced close together.
- The sputter deposition chamber can have a small volume.

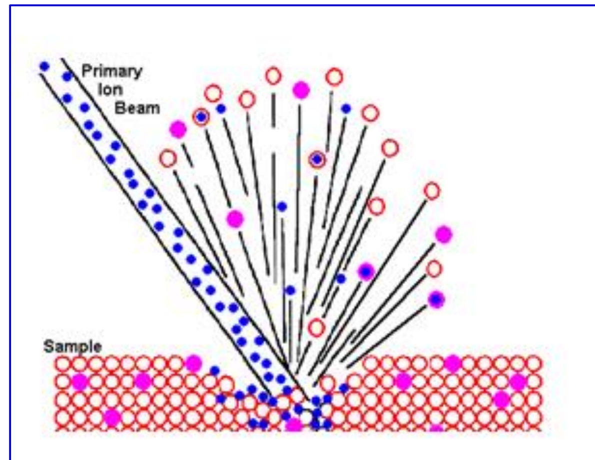
Disadvantages of sputter deposition:

- Sputtering rates are low compared to those that can be attained in thermal evaporation.
- In many configurations, the deposition flux distribution is non-uniform, requiring moving fixturing to obtain films of uniform thickness.
- Sputtering targets are often expensive and material use may be poor.
- Most of the energy incident on the target becomes heat, which must be removed.
- In some cases, gaseous contaminants are "activated" in the plasma, making film contamination more of a problem than in vacuum evaporation.
- In reactive sputter deposition, the gas composition must be carefully controlled to prevent poisoning the sputtering target.

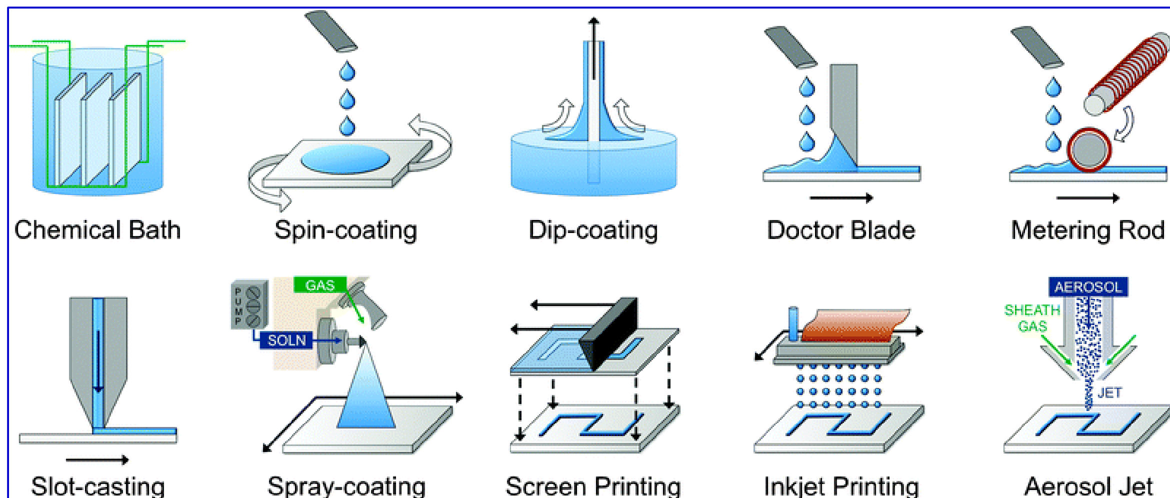
Sputter deposition is widely used to deposit thin film metallization on semiconductor material, coatings on architectural glass, reflective coating on polymers, magnetic films for storage media, transparent electrically conductive films on glass and flexible webs, dry-film lubricants, wear resistant coating on tools and decorative coatings.

Ion beam sputtering

Ion beam sputtering utilizes an ion source to generate a relatively focused ion beam directed at the target to be sputtered. The ion source consists of a cathode and anode with a common central axis. Applying a high voltage field of 2-10 kV to the anode creates an electrostatic field inside the ion source, confining electrons around a saddle point in the center of the source.



When argon gas is injected into the ion source, the high electric field causes the gas to ionize, creating a plasma inside the source region. The ions are then accelerated from the anode region to the exit aperture (cathode) creating a “collimated” ion beam. The resulting ion beam impinges upon a target material and, via momentum transfer between the ion and the target, sputters this material onto the sample.



Molecular beam epitaxy: https://www.youtube.com/watch?v=RhMUGTjbv4g

Thin film deposition: https://www.youtube.com/watch?v=f7UxBawRPj4

Sputtering: https://www.youtube.com/watch?v=9OEz_e9C4KM

Assembly https://www.youtube.com/watch?v=_tJhWw7cvT4

https://www.youtube.com/watch?v=lsf0yox0I2Y

https://www.youtube.com/watch?v=7xunyJwjKl0