Lecture-7

Two-Dimensional Nanostructures (Thin Films) Contd…

(Ref: Guozhong Cao; Nanostructures & Nanomaterial: Synthesis, Properties & Applications)

Physical Vapor Deposition (PVD)

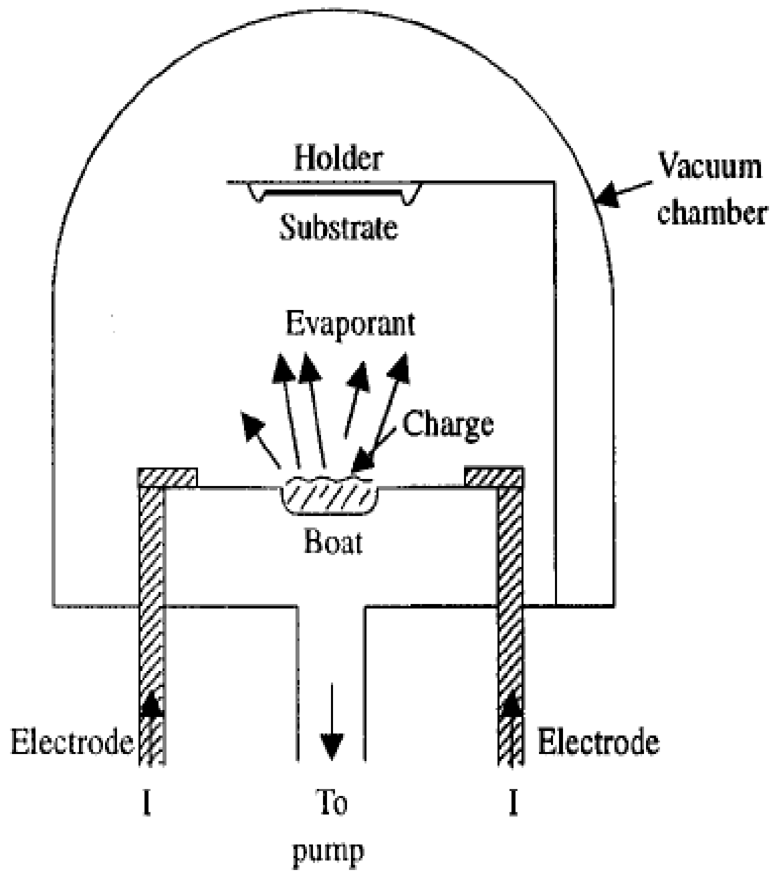
- PVD is a process of transferring growth species from a source or target and deposit them on a substrate to form a film.
- The process proceeds atomistically and mostly involves no chemical reactions.
- Various methods have been developed for the removal of growth species from the source or target.
- The thickness of the deposits can vary from angstroms to millimeters.

- In general, those methods can be divided into two groups: evaporation and sputtering.
- In evaporation, the growth species are removed from the source by thermal means.
- In sputtering, atoms or molecules are dislodged from solid target through impact of gaseous ions (plasma).
- Each group can be further divided into a number of methods, depending on specific techniques applied to activate the source or target atoms or molecules and the deposition conditions applied.

Evaporation

- Useful for the deposition of elemental films.

- Although formation of thin films by evaporation was known about 150 years ago, it acquired a wide range of applications over 50 years when the industrial scale vacuum techniques were developed.



Evaporation…

- The system consists of an evaporation source that vaporizes the desired material and a substrate is located at an appropriate distance facing the evaporation source.
- Both the source and the substrate are located in a vacuum chamber.
- The substrate can be heated or electrically biased or rotated during deposition.
- The desired vapor pressure of source material can be generated by simply heating the source to elevated temperatures.
- The concentration of the growth species in the gas phase can be easily controlled by varying the source temperature and the flux of the carrier gas.

Evaporation…

- The equilibrium vapor pressure of an element can be estimated as:

$$\ln P_e = -\frac{\Delta H_e}{R_g T} + C$$

where; Δh_e is the molar heat of evaporation,

R_g, gas constant,

T, temperature, and

C, a constant.

- However, evaporation of compounds is more complicated, since compounds may undergo chemical reactions, such as pyrolysis, decomposition and dissociation, and the resulting vapor composition often differs from the source composition during evaporation at elevated temperatures.

Evaporation…

- The rate of evaporation is dependent on the material in question:

$\phi_e = \alpha_e N_A(P_e - P_h)/ 2\pi m R_g T)^{1/2}$

where ϕ_e, is the evaporation rate,

α_e the coefficient of evaporation varying between 0 and 1,

N_A, Avogadro's constant,

P_e, the vapor pressure,

P_h, the hydrostatic pressure acting on the source,

m, the molar weight,

R_g, the gas constant and

T, the temperature.

Evaporation…

- When a mixture of elements or compounds is used as a source for the growth of a complex film, the chemical composition of the vapor phase is most likely to be different from that in the source.
- Adjusting the composition/molar ratio of the constituents in the source may help.
- However, the composition of the source would change as the evaporation proceeds, since one element may evaporate much faster than another resulting in the depletion of the first element.
- As a result, the composition in the vapor phase will change.
- For a multi component system, the chemical composition of evaporated film is likely to be different from that of the source and varies with thickness.
- In general, it is difficult to deposit complex films using evaporation method.

Evaporation…

- Deposition of thin films by evaporation is carried out in a low pressure (10^{-3} – 10^{-10} torr);
- Atoms and molecules in the vapor phase do not collide with each other prior to arrival at the growth surface, since the mean free path is very large as compared to the source-to-substrate distance.
- The transport of atoms or molecules from the source to the growth substrate is straightforward along the line of sight,
- Therefore the conformal coverage is relatively poor and a uniform film over a large area is difficult to obtain.

- Some special arrangements have been developed to overcome such a shortfall; these include

    (i) using multiple sources instead of single point source,

    (ii) rotating the substrates,

    (iii) loading both source and substrate on the surface of a sphere, and

    (iv) combination of all the above.

- In addition to evaporation of source by resistance heat, other techniques have been developed and have attracted increasing attention and gained more popularity.
- For example, laser beams have been used to evaporate the material.
- Absorption characteristics of the material to be evaporated determine the laser wavelength to be used.
- In order to obtain the high power density required in many cases, pulsed laser beams are generally employed.
- Such a deposition process is often referred to as Laser Ablation.
- Laser ablation has proven to be an effective technique for deposition of complex films including complex metal oxides such as high T, superconductor films.

- One of the great advantages that laser ablation offers is the control of the vapor composition.
- In principle, the composition of the vapor phase can be controlled as that in the source.
- The disadvantages of laser ablation include the complex system design, not always possible to find desired laser wavelength for evaporation, and the low energy conversion efficiency.
- Electron beam evaporation is another technique, but it is limited to the case that the source is electrically conductive.
- The advantages of electron beam evaporation include a wide range of controlled evaporation rate due to a high power density and low contamination.

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