Lecture-8

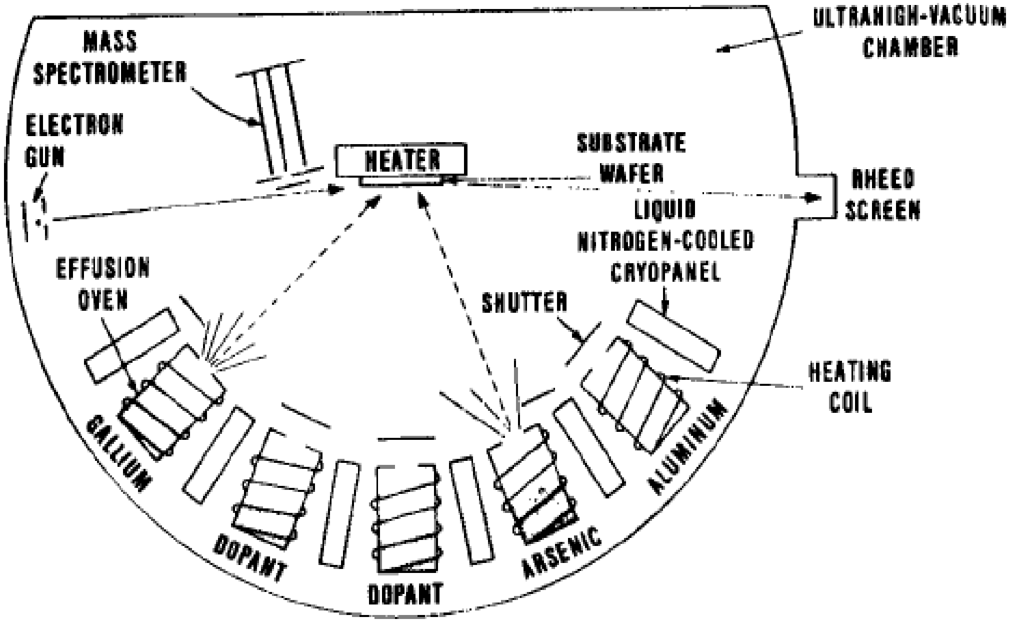
Two-Dimensional Nanostructures (Thin Films) Contd…

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

Molecular Beam Epitaxy (MBE)

- MBE can be considered as a special case of evaporation for single crystal film growth, with highly controlled evaporation of a variety of sources in ultrahigh-vacuum of typically -10^{-10} torr.
- Besides the ultrahigh vacuum system, MBE mostly consists of real time structural and chemical characterization capability, including reflection high energy electron diffraction (RHEED), X-ray photoelectric spectroscopy (XPS), Auger electron spectroscopy (AES).
- Other analytic instruments may also been attached to the deposition chamber or to a separate analytic chamber, from which the grown films can be transferred to and from the growth chamber without exposing to the ambient.

- In MBE, the evaporated atoms or molecules from one or more sources do not interact with each other in the vapor phase under such a low pressure.
- Although some gaseous sources are used in MBE, most molecular beams are generated by heating solid materials placed in source cells, which are referred to as effusion cells or Knudsen cells.
- A number of effusion cells are radically aligned with the substrates as shown below:



- The source materials are most commonly raised to the desired temperatures by resistive heating.
- The mean free path of atoms or molecules (~100 m) far exceeds the distance between the source and the substrate (typically ~30 cm) inside the deposition chamber.
- The atoms or molecules striking on the single crystal substrate results in the formation of the desired epitaxial film.
- The extremely clean environment, the slow growth rate, and independent control of the evaporation of individual sources enable the precise fabrication of nanostructures and nanomaterials at a single atomic layer.

Molecular beam epitaxy (MBE)……

- Ultrahigh vacuum environment ensures absence of impurity or contamination, and thus a highly pure film can be readily obtained.
- Individually controlled evaporation of sources permits the precise control of chemical composition of the deposit at any given time.
- The slow growth rate ensures sufficient surface diffusion and relaxation so that the formation of any crystal defects is kept minimal.
- The main attributes of MBE include:

  1) A low growth temperature (e.g. 550°C for GaAs) that limits diffusion and maintains hyper abrupt interfaces, which are very important in fabricating two-dimensional nanostructures or multilayer structures such as quantum wells.

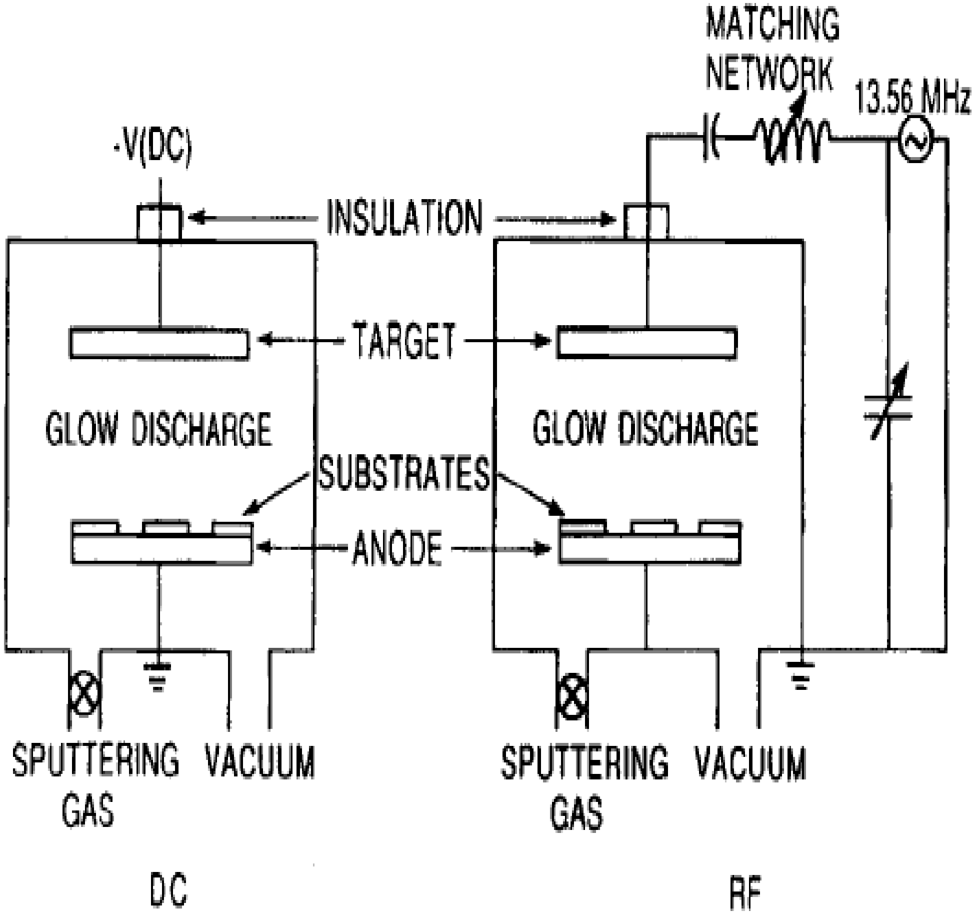
2) A slow growth rate that ensures a well controlled two-dimensional growth at a typical growth rate of 1 μm/h . A very smooth surface and interface is achievable through controlling the growth at the monoatomic layer level.

3) A simple growth mechanism compared to other film growth techniques ensures better understanding due to the ability of individually controlled evaporation of sources.

4) A variety of in situ analysis capabilities provide invaluable information for the understanding and refinement of the process.

Sputtering

- Sputtering is to use energetic ions to knock atoms or molecules out from a target that acts as one electrode and subsequently deposit them on a substrate acting as another electrode.



Sputtering…

- Let us take the dc discharge as an example to illustrate the process.
- Target and substrate serve as electrodes and face each other in a typical sputtering chamber.
- An inert gas, typically argon with a pressure usually ranging from a few to 100 m torr, is introduced into the system as the medium to initiate and maintain a discharge.
- When an electric field of several kilovolts per centimeter is introduced or a dc voltage is applied to the electrodes, a glow discharge is initiated and maintained between the electrodes.

Sputtering…

- Free electrons will be accelerated by the electric field and gain sufficient energy to ionize argon atoms.
- The gas density or pressure must not be too low, or else the electrons will simply strike the anode without having gas phase collision with argon atoms.
- However, if the gas density or pressure is too high, the electrons will not have gained sufficient energy when they strike gas atoms to cause ionization.

Sputtering…

- Resulting positive ions, Ar^+, in the discharge ambience, strikes the cathode (the source target) resulting in the ejection of neutral target atoms through momentum transfer.
- These atoms pass through the discharge and deposit on the opposite electrode (the substrate with growing film).
- In addition to the growth species, i.e. neutral atoms, other negatively charged species under the electric field will also bombard and interact with the surface of the substrate or growth film.

Sputtering…

- For the deposition of insulating films, an alternate electric field is applied to generate plasma between two electrodes.
- Typical RF frequencies employed range from 5 to 30 MHz.
- However, 13.56 MHz has been reserved for plasma processing by the Federal Communications Commission and is widely used.
- The key element in RF sputtering is that the target self-biases to a negative potential and behaves like a dc target.
- Such a self-negative target bias is a consequence of the fact that electrons are considerably more mobile than ions and have little difficulty in following the periodic change in the electric field.

- To prevent simultaneous sputtering on the grown film or substrate, the sputter target must be an insulator and be capacitively coupled to the RF generator.
- This capacitor will have a low RF impedance and will allow the formation of a dc bias on the electrodes. Details are given at..

http://books.google.co.in/books?id=bBjpoLsyycMC&pg=PA140&lpg=PA140&dq=sputtering+for+insulating+films&source=web&ots=Dy6uaxRHqE&sig=2mHx5GjnQTEbe6d9_t0MWbQsToY&hl=en#PPA139,M1

Sputtering…

- Sputtering a mixture of elements or compounds will not result in a change of composition in the target and thus the composition of the vapor phase will be the same as that of the target and remain the same during the deposition.
- Many modifications have been made to enhance or improve the deposition process and resulted in the establishment of hybrid and modified PVD processes.
- For example, magnetic field has been introduced into sputtering processes to increase the residence time of growth species in the vapor phase; such sputtering is referred to as magnetron sputtering.
- Reactive gases have also been introduced into the deposition chamber to form compound films, which are known as reactive sputtering.

Comparison of Evaporation and Sputtering…

• Evaporation uses low pressures typically ranging from 10^{-3} to 10^{-10} torr.	• Sputtering requires a relatively high pressure typically of ~100 torr.
• Describable by thermo-dynamical equilibrium.	• Not.
• The growth surface is not activated.	• Growth surface is constantly under electron bombardment and thus is highly energetic.
• Evaporated films consist of large grains.	• Smaller grains with better adhesion to the substrates.

Prof. S. K. Tripathi
Department of Physics
School of Physical Sciences
Mahatma Gandhi Central University

Course Name: Nano Materials and Applications
Course Code: PHYS3024