

Lecture-6

Two-Dimensional Nanostructures (Thin Films)

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

Two-Dimensional Nanostructures: Thin Films

Film growth methods can be generally divided into two groups:

- Vapor-Phase Deposition

Evaporation, Molecular beam epitaxy (MBE), Sputtering, Chemical Vapor Deposition (CVD), and Atomic Layer Deposition (ALD).

- Liquid-Based Growth

Electrochemical Deposition, Chemical Solution Deposition (CSD), Langmuir-Blodgett films and Self-Assembled Monolayers (SAMs).

Fundamentals of Film Growth

- Growth of thin films, is a phase transformation, which involves the processes of nucleation and growth on the substrate or growth surfaces.
- The nucleation process plays a very important role in determining the crystallinity and microstructure of the resultant films.
- For the deposition of thin films with thickness in the nanometer region, the initial nucleation process is even more important.
- The size and the shape of the initial nuclei are assumed to be solely dependent on the change of volume of Gibbs free energy, due to supersaturation, and the combined effect of surface and interface energies governed by Young's equation.

Vacuum Science

- In a gas phase, gas molecules are constantly in motion and colliding among themselves as well as with the container walls.
- Pressure of a gas is the result of momentum transfer from the gas molecules to the walls, and is the most widely quoted system variable in vacuum technology.
- The mean distance traveled by molecules between successive collisions is called the mean free path and is an important property of the gas that depends on the pressure, given by:

$$\lambda_{\text{mpf}} = 5 \times 10^{-3} / P$$

where λ_{mpf} is mean free path (in centimeter) and P is the pressure in torr.

When pressure is below 10^{-3} torr, the gas molecules in film deposition and characterization systems virtually collide only with the walls of the vacuum chamber, i.e. there is no collision among gas molecules.

Vacuum Science...

- The gas impingement flux in the film deposition is a measure of the frequency with which gas molecules impinge on or collide with a surface, and is the most important parameter.
- It is because for film deposition, only molecules impinging onto the growth surface will be able to contribute to the growth process.
- The number of gas molecules that strike a surface per unit time and area is defined as the gas impingement flux,

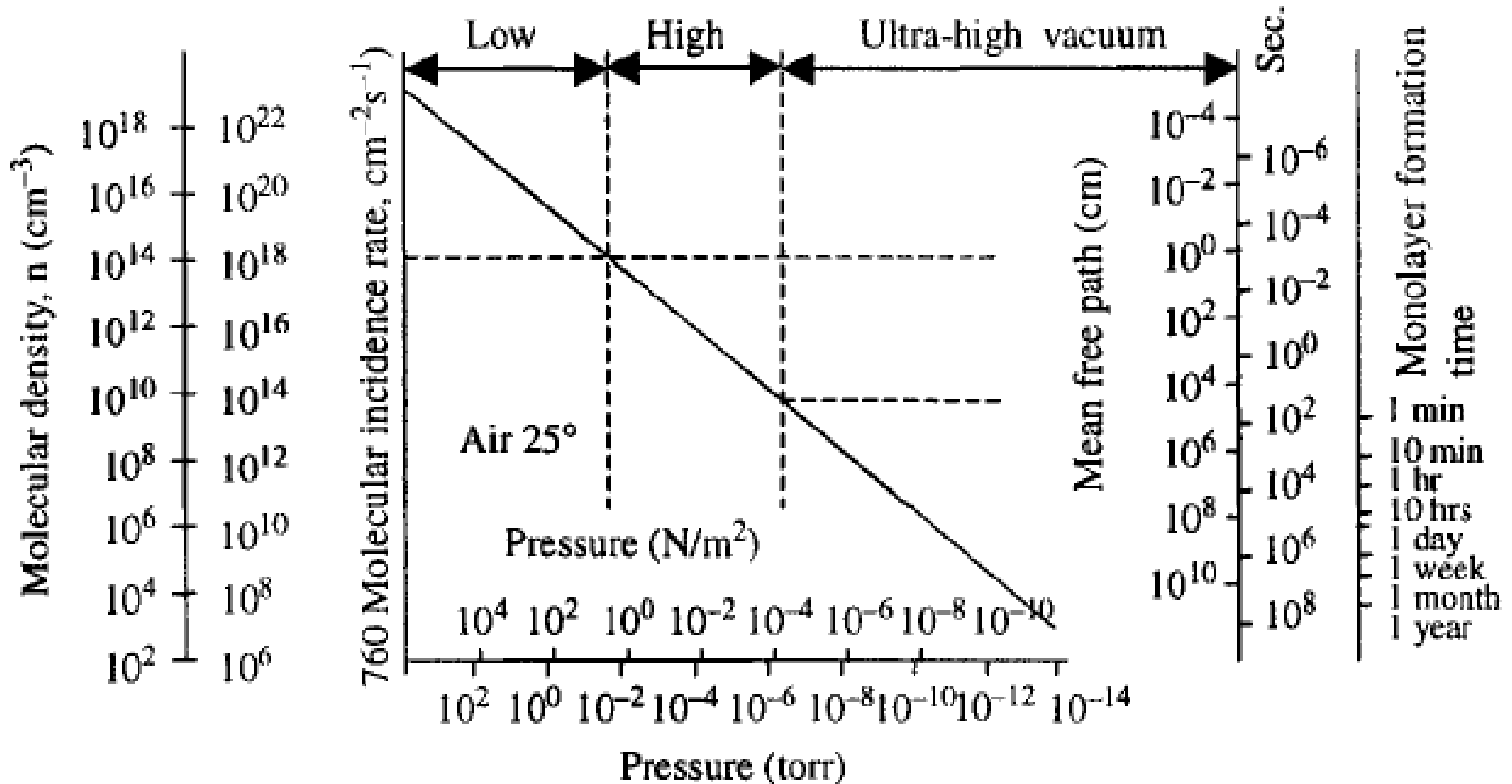
$$\phi = 3.513 \times 10^{22} P / (MT)^{1/2}$$

where P is the pressure in torr,

M is the molecular weight and

T is temperature.

Vacuum Science...



Summary of molecular density, incident rate, mean free path, and monolayer formation time as a function of pressure.

Ref: A. Roth, *Vacuum Technology*, North-Holland, Amsterdam, 1976

Vacuum Science...

- Film deposition processes, 'evaporation' requires a vacuum between the high and ultrahigh regimes, whereas sputtering and low pressure chemical vapor deposition are accomplished at the border between the medium and high vacuum ranges.
- Of the analytical instruments, electron microscopes operate in high vacuum, and surface analytical equipment have the most stringent cleanliness requirements and are operative only under ultrahigh vacuum conditions.

Vacuum Science...

- GAS FLOW: gas flow can be divided into three regimes: molecular flow, intermediate flow and viscous flow.
- The above gas flow can be defined by the magnitude of the Knudsen number, K_n , given by:

$$K_n = D / \lambda_{\text{mpf}}$$

where D is the characteristic dimension of the system,

e.g. the diameter of a pipe, and

λ_{mpf} is the gas mean free path.

Vacuum Science...

- Viscous flow is a bit complex and can be further divided into laminar flow, turbulent flow and transition flow.
- At a low gas flow velocity, the flow is laminar where layered, parallel flow lines may be visualized, no perpendicular velocity is present, and mixing inside the gas is by diffusion only.
- In this flow, the velocity is zero at the gas-wall interface and gradually increases as moving away from the interface, reaching a maximum at the center when flowing inside a pipe.

Vacuum Science...

- Flow behavior can be defined by the so-called Reynolds number, Re , which is given below for a gas flow inside a pipe:

$$Re = D \cdot v \cdot \rho / \eta$$

where 'D' is the diameter of the pipe,

'v' is the velocity,

' ρ ' is the density, and

' η ' is the viscosity of the gas.

Vacuum Science...

- Laminar flow corresponds to a small $Re < 2100$.
- At a high gas velocity, the flow is turbulent, where the gas is constantly under intermixing, where $Re > 4000$.
- At $2100 < Re < 4000$, a transition from laminar to turbulent flow occurs and is referred to as transition flow.
- There is always a laminar flow near to the solid surface in both turbulent and transition flows, since the friction viscous forces a deceleration of the gas at the surface.

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