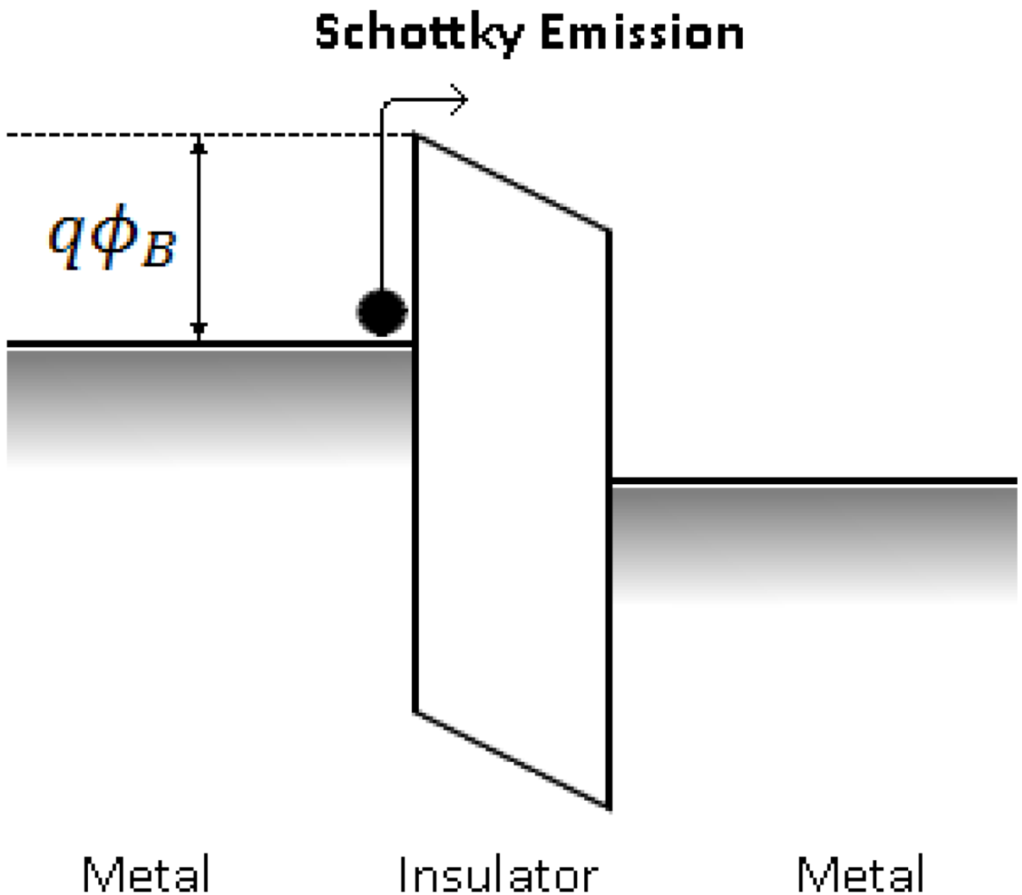
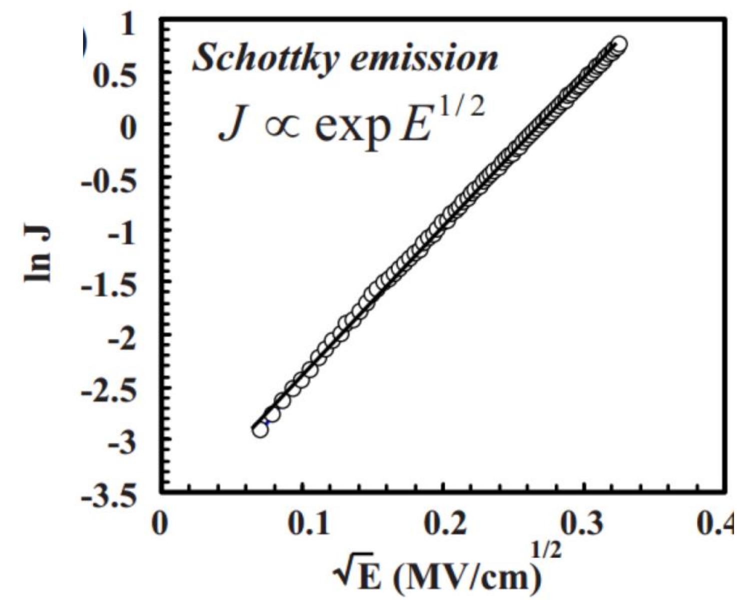
DSE CLASS

CONDENSED MATTER PHYSICS

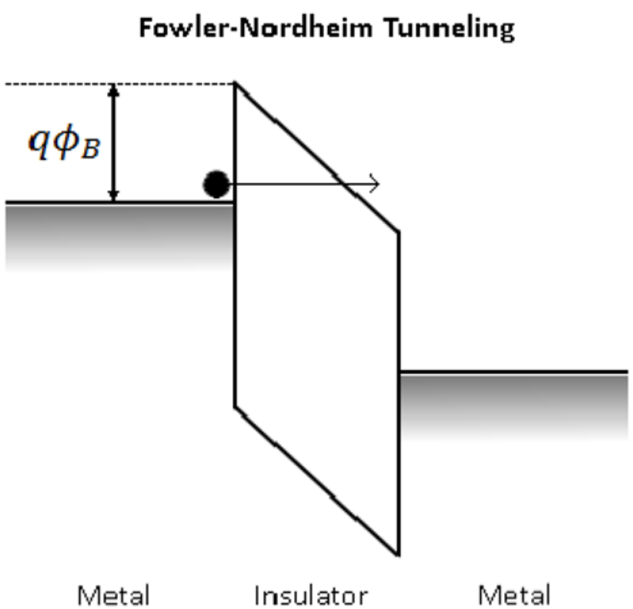
Lecture-12

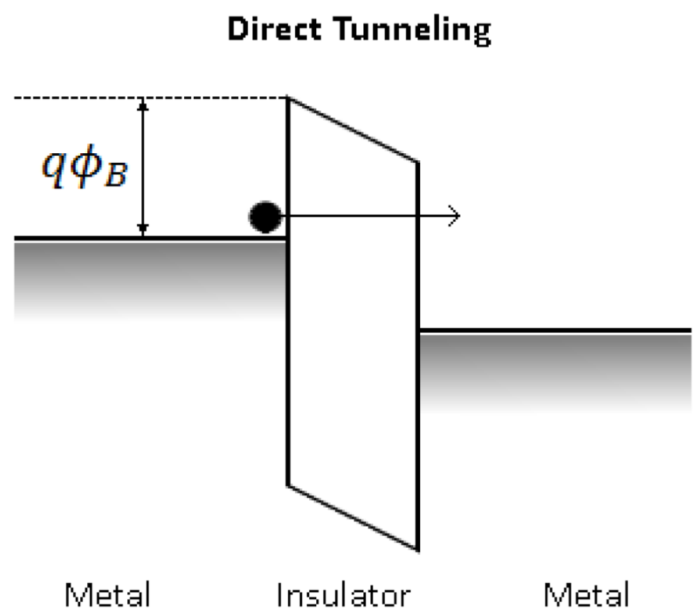
The Schottky or thermionic emission happens when thermally-activated electrons injected over the energy barrier into the conduction band of the oxide





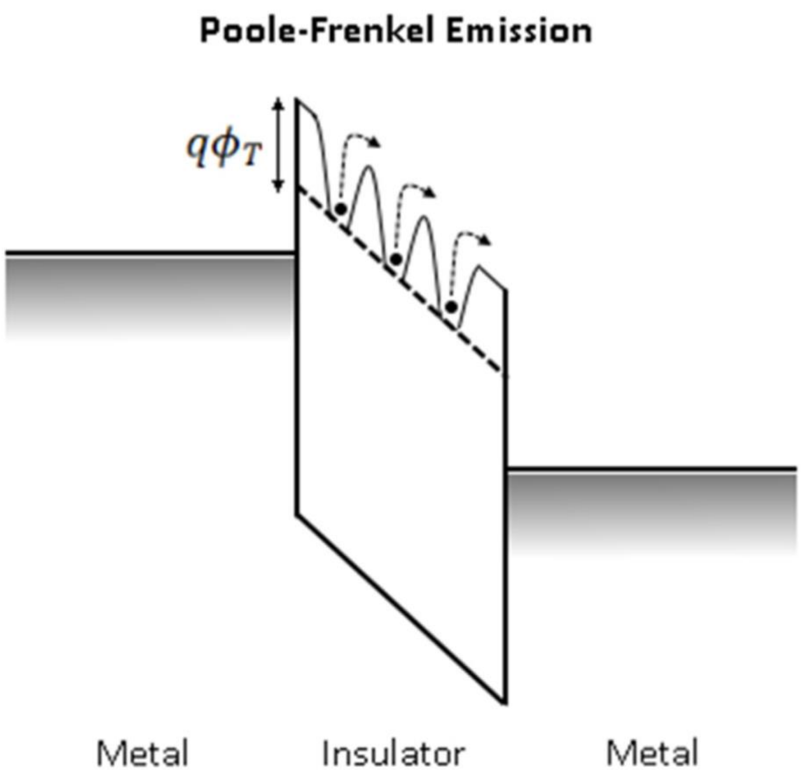
In the presence of high electric field, the Fowler-Nordheim and direct tunneling across the oxide may take place. Generally, direct tunneling is more dominant in oxide thinner than 3 nm, while F-N tunneling is usually more dominant at thicker oxide

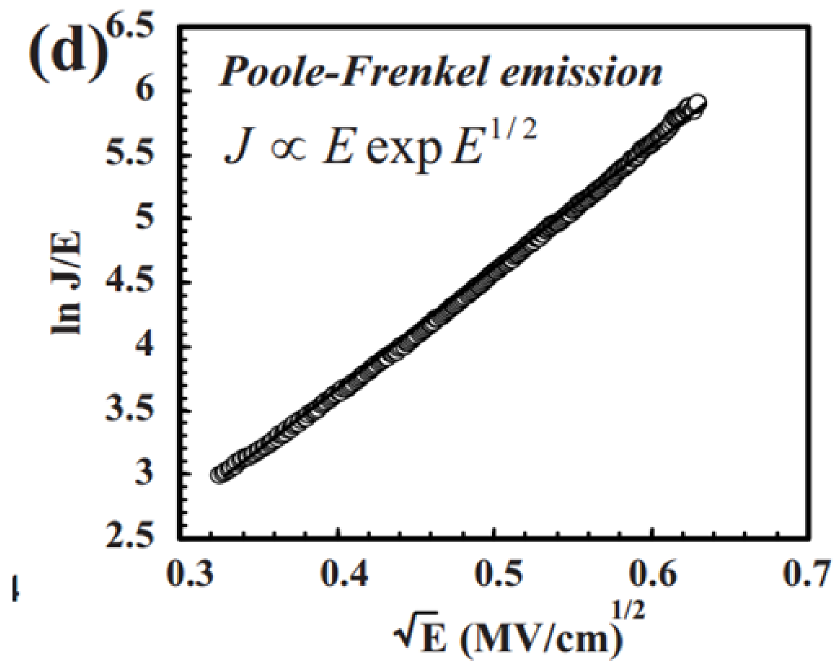




Poole-Frenkel (P-F) Emission

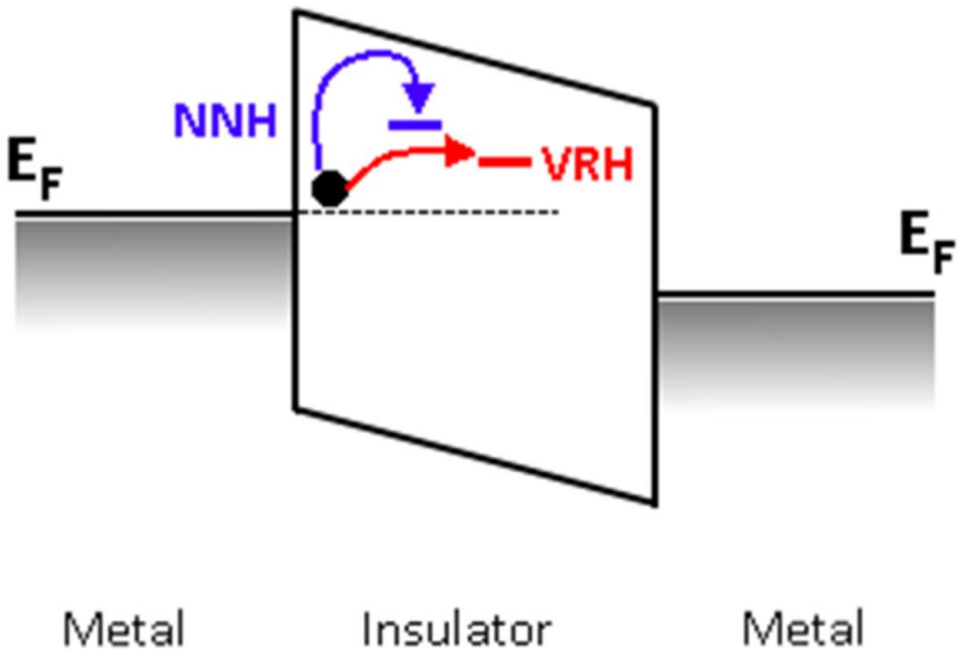
The P-F emission happens when trapped electrons get excited into the conduction band of the oxide. The electric field decreases the Coulombic potential barrier of the electrons and subsequently increases its probability for being thermally excited out from the traps

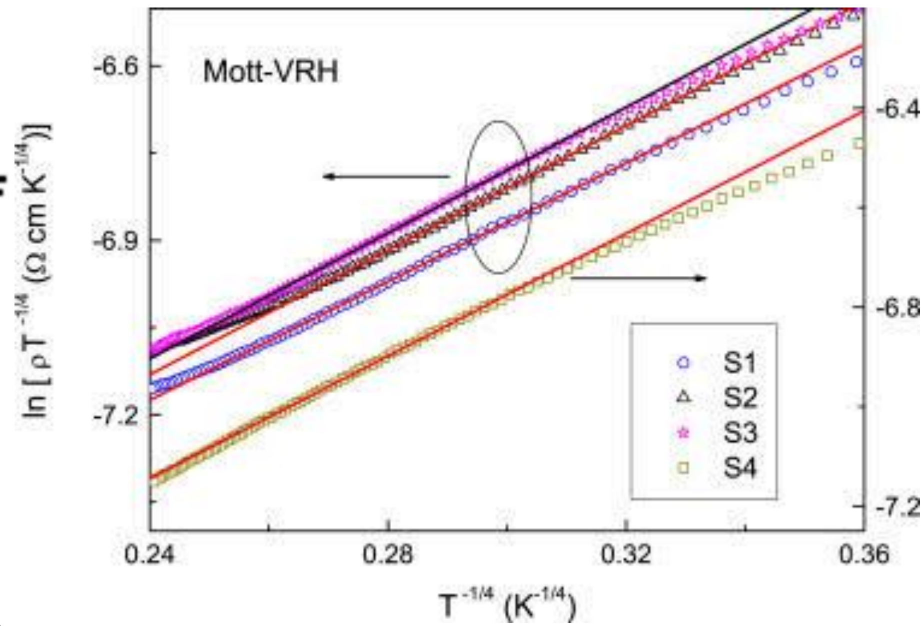




Nearest Neighbor Hopping (NNH)

NNH also known as fixed range hopping (FRH). Oxide layer often contains defects known as traps.



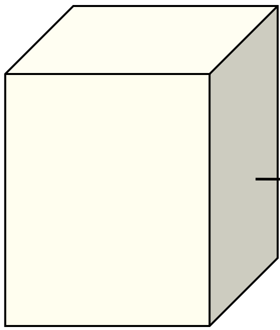


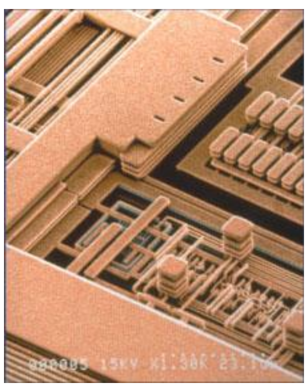
Mott Variable Range Hopping (VRH)

In addition to NNH, Mott VRH is another widely studied hopping conduction mechanism. In contrast with NNH, where the trap electrons are expected to hop into the nearest neighboring trap, the electrons under the VRH scheme may hop into traps that are further away but have lower trap energy.

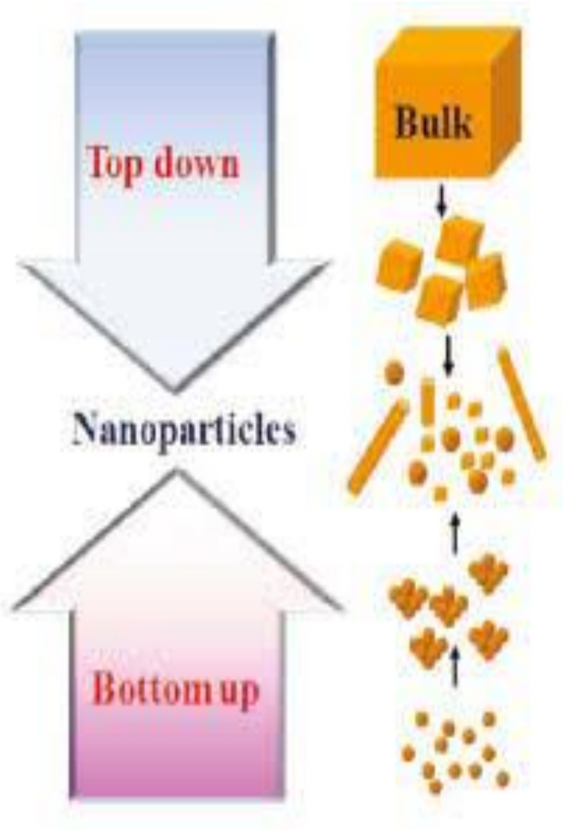
Nanofabrication

Top-Down



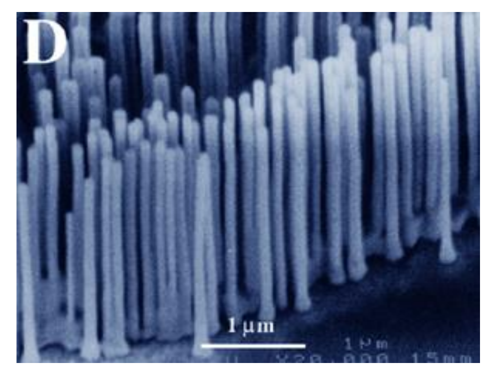


Optical lithography
Electron beam lithography
Top-down approach



Bottom-Up

Self-assembly of nanoparticles, individual atoms, molecules
Bottom-up approach



Chemical deposition
Bottom-up approach

Thin Film Deposition

Physical Vapor Deposition (PVD)

Film is formed by atoms directly transported from source to the substrate through gas phase

Evaporation

- Thermal evaporation
- E-beam evaporation

Sputtering

- DC sputtering
- DC Magnetron sputtering
- RF sputtering

Chemical Vapor Deposition (CVD)

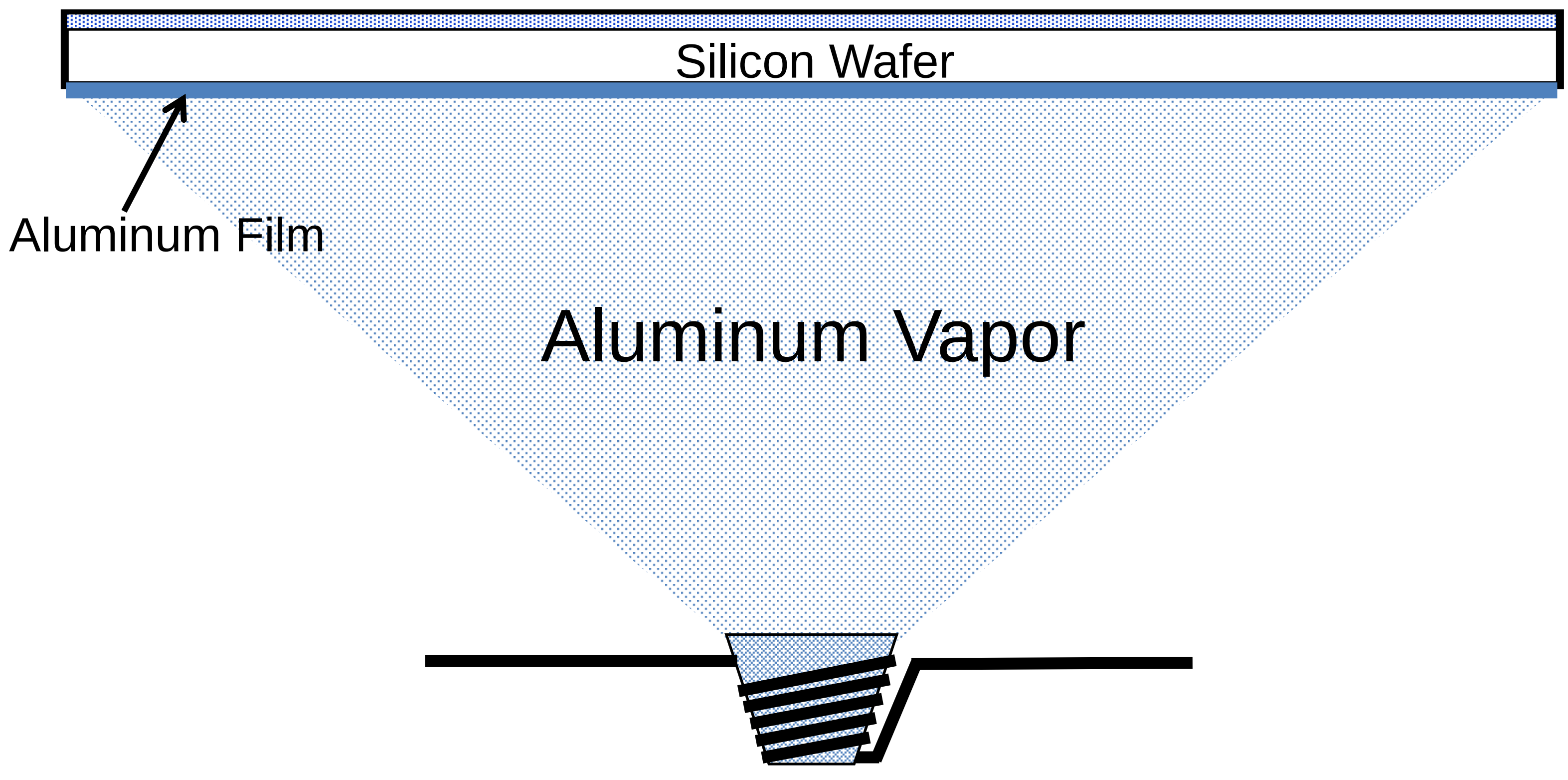
Film is formed by chemical reaction on the surface of substrate

- Low-Pressure CVD (LPCVD)
- Plasma-Enhanced CVD (PECVD)
- Atmosphere-Pressure CVD (APCVD)
- Metal-Organic CVD (MOCVD)

Evaporation

In order to evaporate a material, it must be heated to a temperature at which its vapor pressure is 10^{-3} Torr or higher.

E.g., aluminum must be heated to 1000°C or more.



Evaporation

There are two common ways to heat the source material :

- *resistive heating*
- *electron-beam heating*.

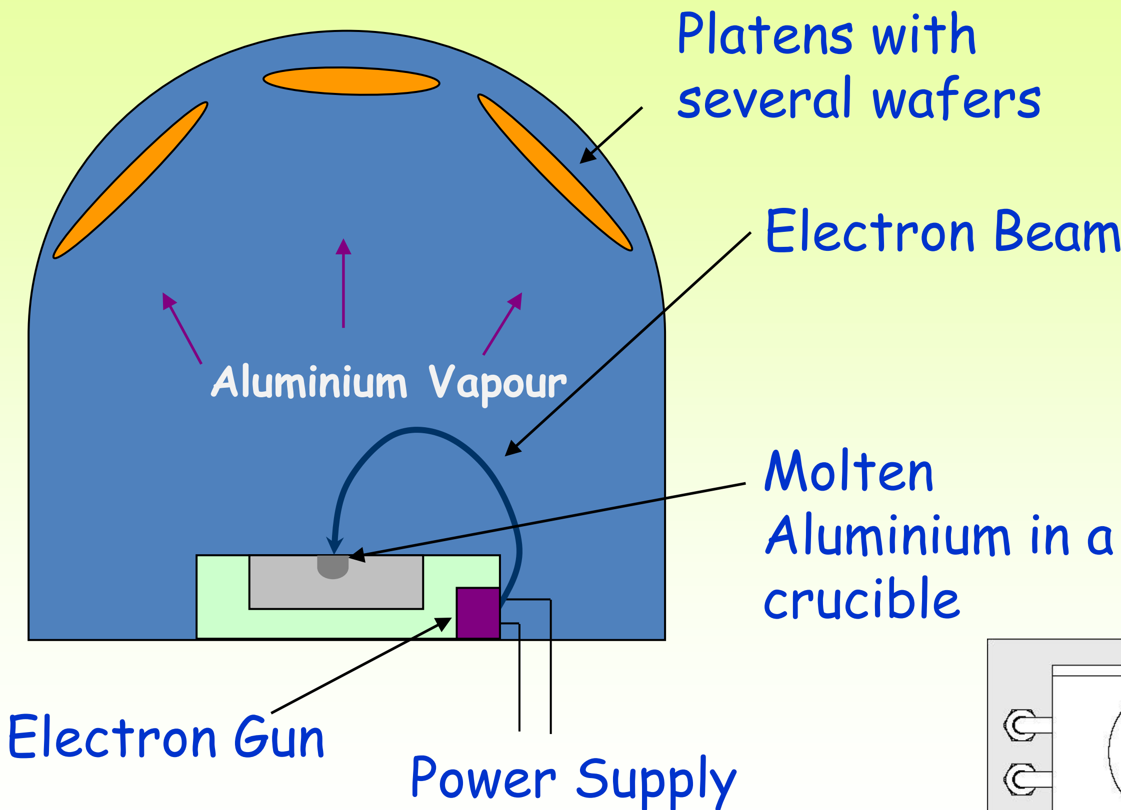
Resistive heating uses electric current flow through a tungsten filament to heat the source material.

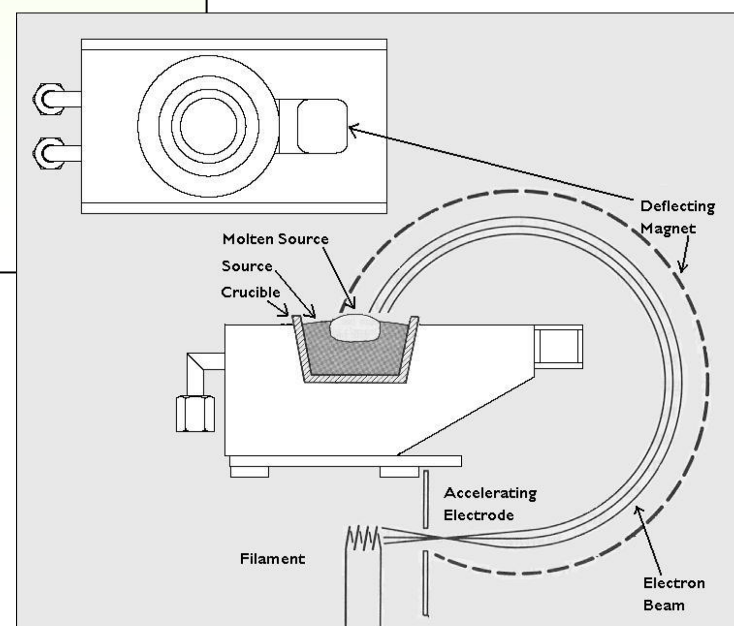
The source material can be placed directly on the tungsten filament, or it can be put in a crucible that is heated by the filament.

Evaporation

In electron-beam (e-beam) evaporation systems, a high intensity beam of electrons, given off by a charged tungsten filament under high vacuum, with energy up to 15 keV, is focused on the source material.

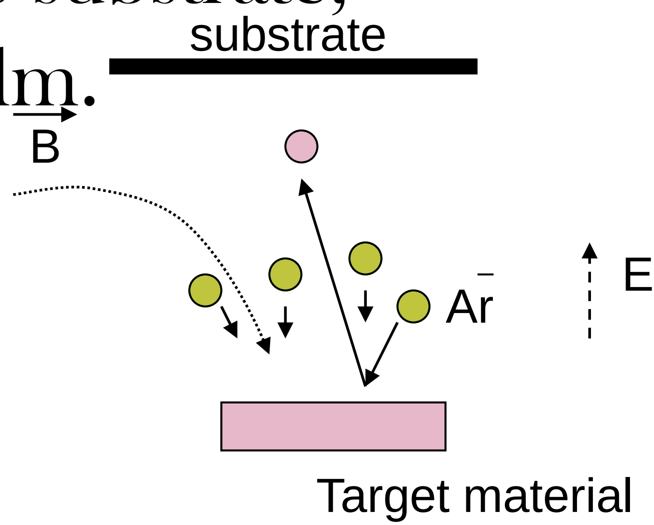
Electron bombardment heats the source material to the temperature required for evaporation.


Platens with
several wafers
Electron Beam
Aluminium Vapour
Molten
Aluminium in a
crucible
Electron Gun
Power Supply

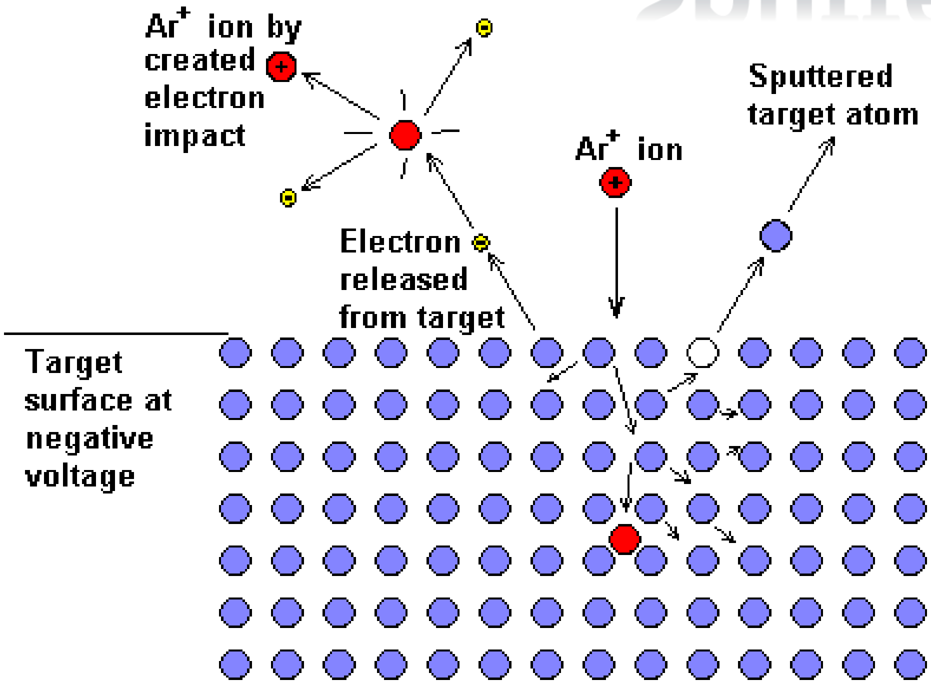

Deflecting
Magnet
Molten Source
Source
Crucible
Accelerating
Electrode
Filament
Electron
Beam

Sputtering

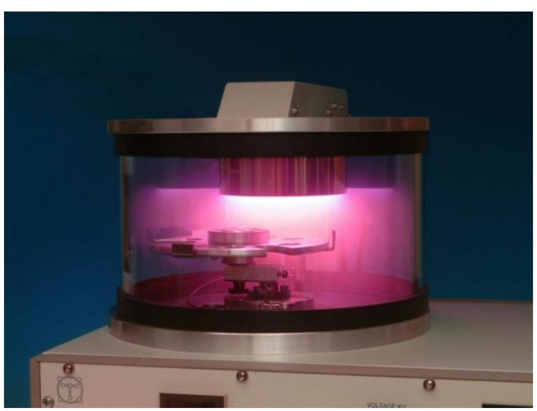
- In sputtering, the source material is usually in the form of a sheet or plate, called a ***target***.
- Sputtering is achieved by bombarding the target with energetic ions, typically Ar^{+}.
- Atoms on the surface of the target are dislodged by this bombardment and fly off .
- These atoms then impinge on the substrate, resulting in deposition of a thin film.

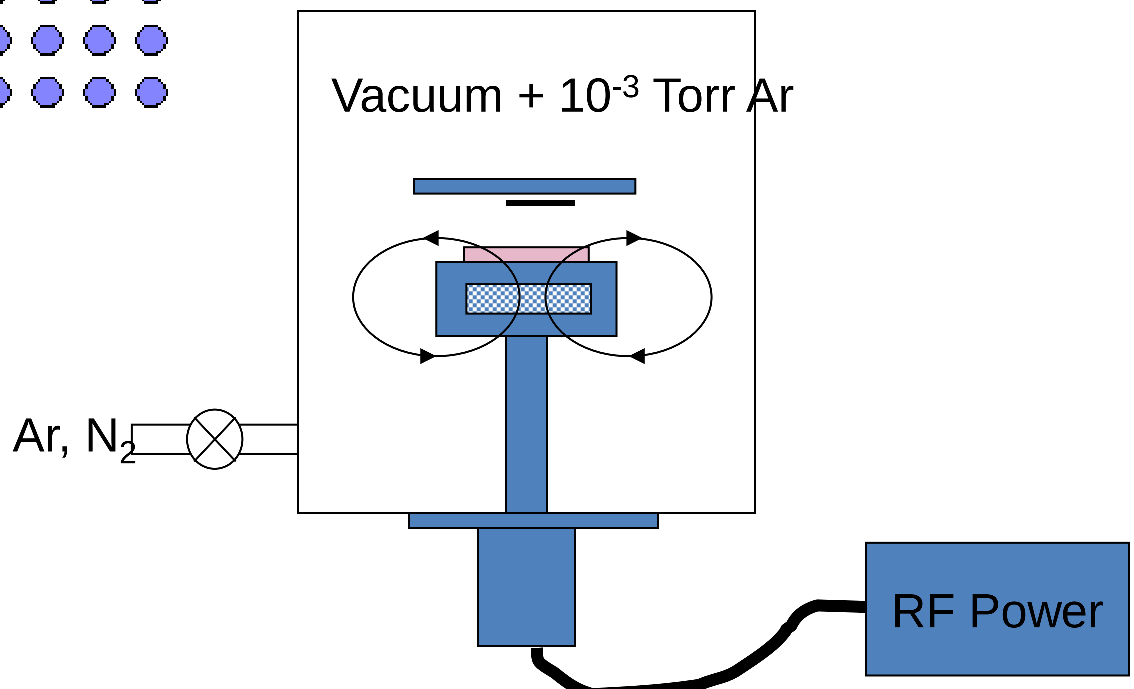


Sputtering

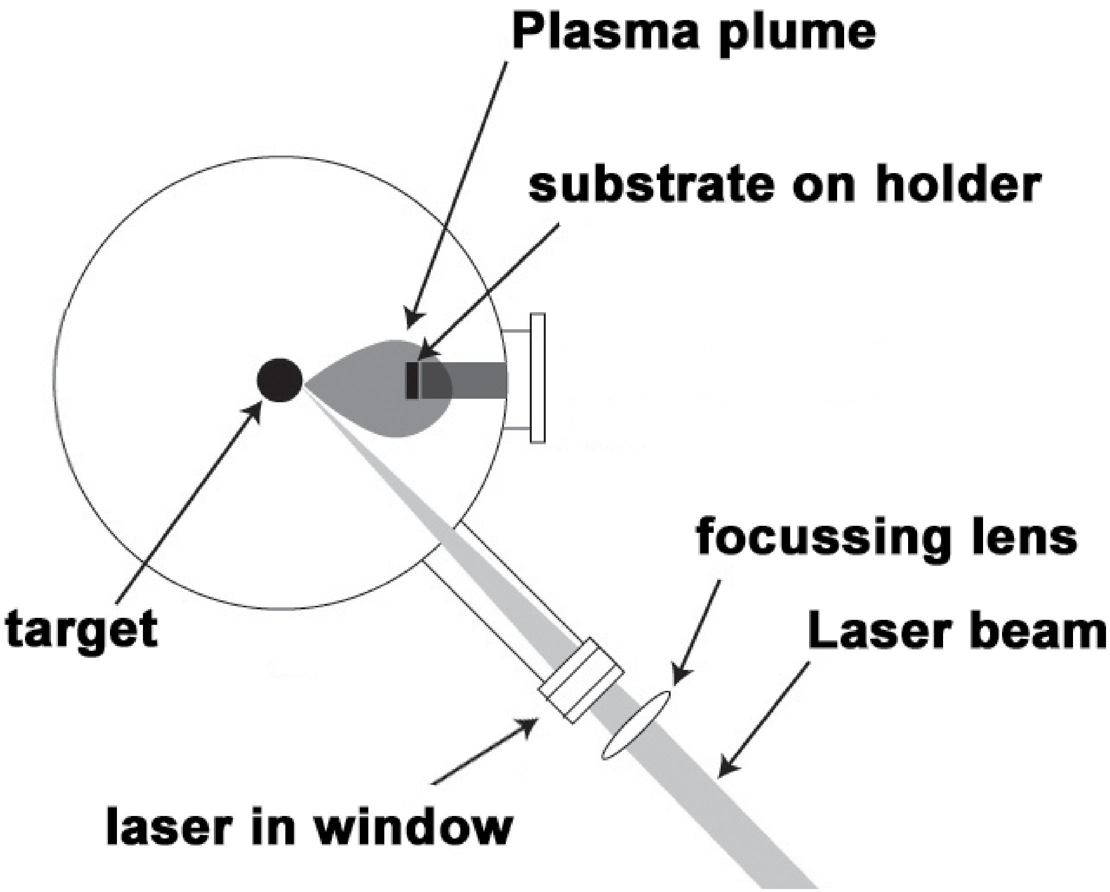


- In sputtering, energetic ions from the plasma of a gaseous discharge bombard a target that is the cathode of the discharge. Target atoms are ejected and impinge on a substrate, forming a coating.
- **Direct current sputtering**
- **Direct current reactive sputtering**
- **Radio-frequency sputtering**





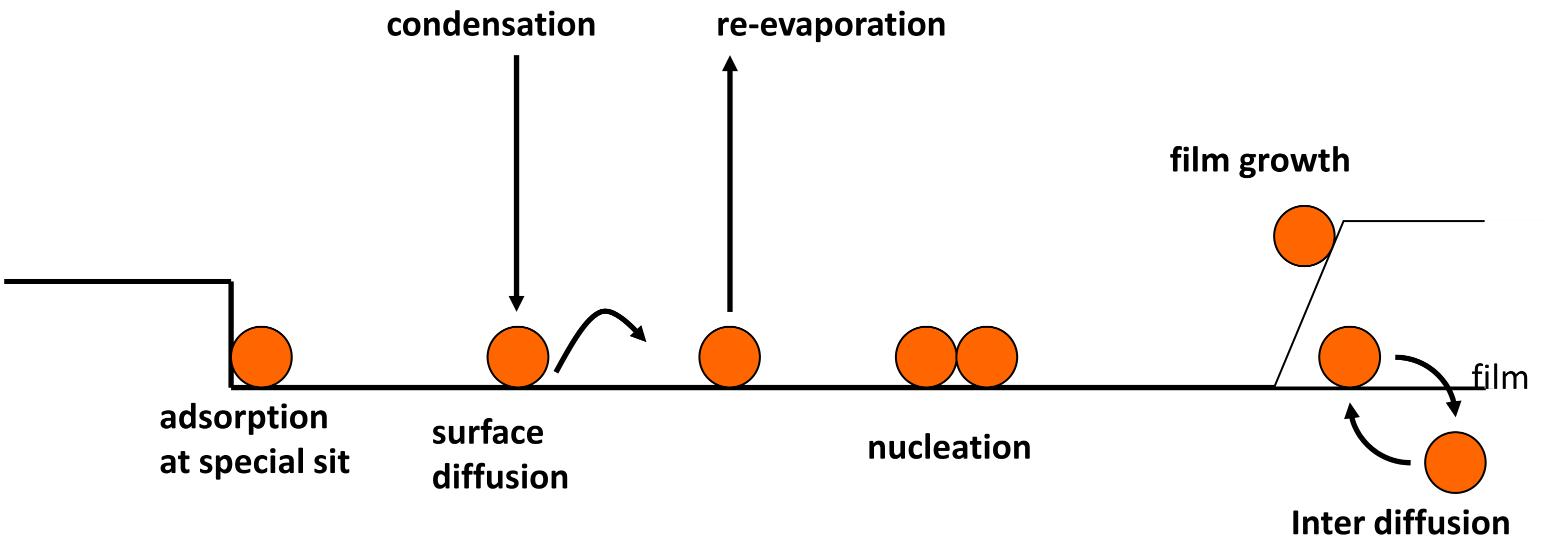
Pulsed Laser Deposition



A high power pulsed laser beam is focused inside a vacuum chamber to strike a target of the material that is to be deposited. This material is vaporized from the target (in a plasma plume) which deposits it as a thin film on a substrate.

Condensation

Condendation is the change of the physical state of matter from gaseous phase into liquid phase or solid phase, and the reverse is vaporization.

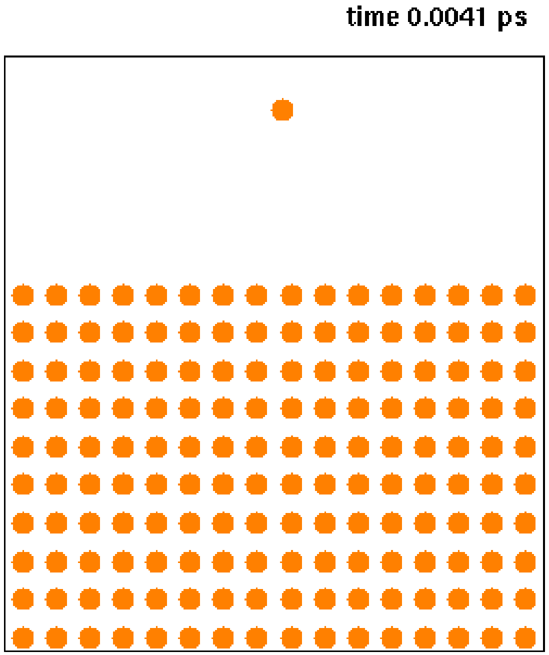


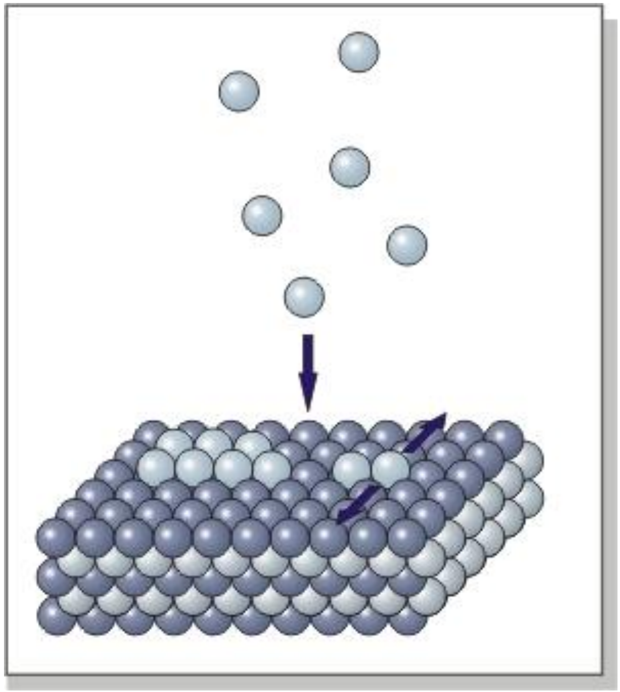
- Adsorption of atoms from gaseous phase
- Cluster formation
- Critical size islands growth
- Coalescence of neighboring islands
- Percolation of islands network
- Continuous film growth

MBE

"*Molecular Beam Epitaxy is a versatile technique for growing thin epitaxial structures made of semiconductors, metals or insulators.*"

In a ultra-high vacuum, a beam of atoms or, more general, a beam of molecules is directed towards a crystalline substrate such that the atoms or molecules stick at the substrate's surface forming a new layer of deposited material.

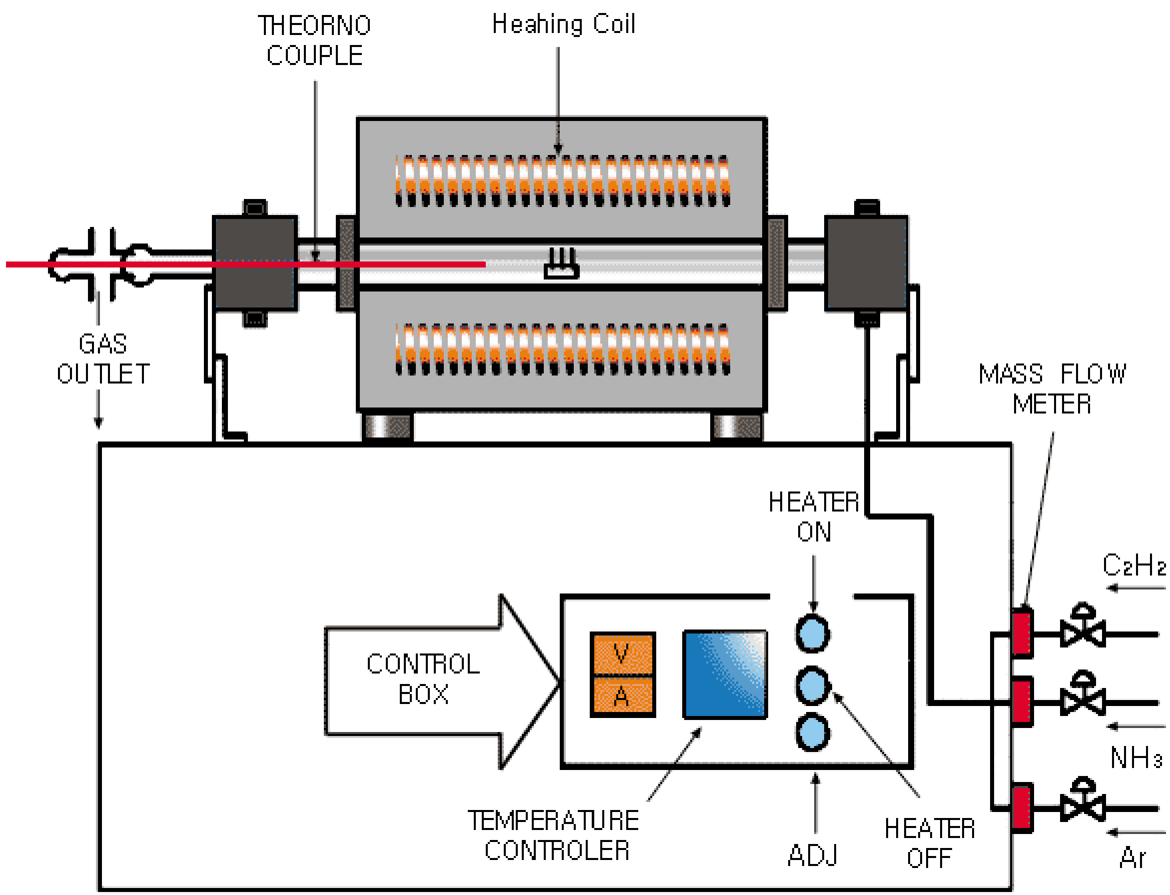


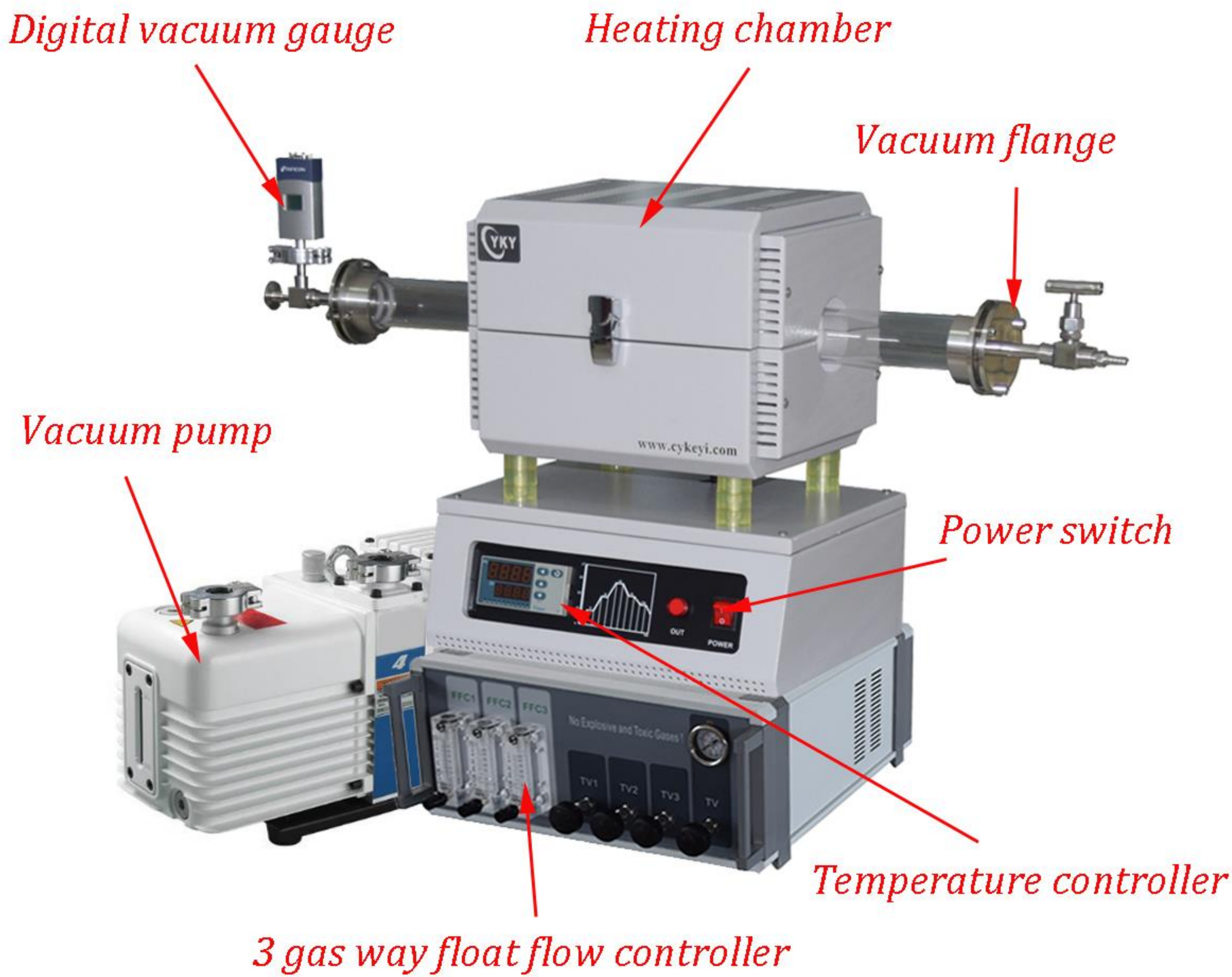


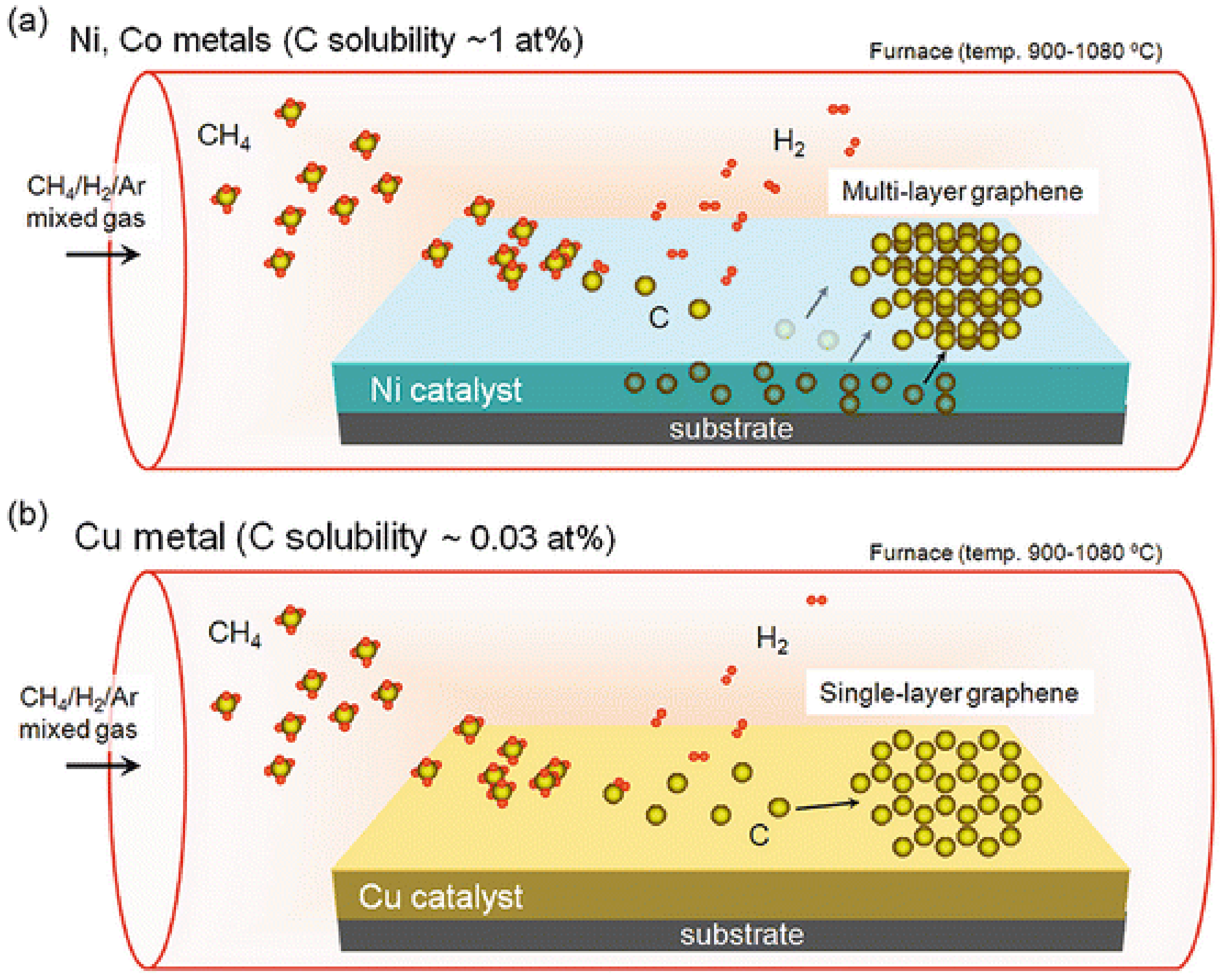
MBE and surface analysis chamber

Chemical Vapor Deposition

Chemical Vapor Deposition (CVD) is the formation of a solid material (insulator, metal, or semiconductor) from the reaction of source gases (or vaporized liquids).




Digital vacuum gauge
Heating chamber
Vacuum flange
CYKY
www.cykeyi.com
Vacuum pump
Power switch
OUT
POWER
FFC1
FFC2
FFC3
No Explosive and Toxic Gases!
TV1
TV2
TV3
TV
Temperature controller
3 gas way float flow controller



(a)
Ni, Co metals (C solubility ~1 at%)
Furnace (temp. 900-1080 °C)
CH4
H2
CH4/H2/Ar mixed gas
Multi-layer graphene
C
Ni catalyst
substrate
(b)
Cu metal (C solubility ~ 0.03 at%)
Furnace (temp. 900-1080 °C)
CH4
H2
CH4/H2/Ar mixed gas
Single-layer graphene
C
Cu catalyst
substrate

CVD has a number of advantages over physical vapor deposition:

- ❖ The reaction can be arranged to be selective more easily, depositing material only in certain regions of the substrate rather than covering it with a blanket layer.
- ❖ CVD covers a rough surface relatively uniformly, tracking the morphology rather than resulting in thin, low quality coatings on vertical walls of the substrate, as is the case for physical vapor deposition methods.

Other advantages :

- CVD uses source materials that flow into the process chamber from external reservoirs that can be refilled without contamination of the growth environment.
- It does not require very high vacuum levels.
- It can generally process substrates in larger batches than evaporation.

Counterbalancing these advantages:

CVD source materials are generally highly toxic or flammable, requiring great care in the design and operation of a CVD process system.

CVD also frequently requires high temperatures.

For microelectronics manufacturing the benefits generally outweigh the problems.
Thus, most device makers use CVD when possible rather than, for example, MBE.