VLSI Technology

(EC 617)

Dr. Vivek Garg

Department of Electronics Engineering

S. V. National Institute of Technology (SVNIT)
Surat

email: vivekg@eced.svnit.ac.in; vivekgarg0101@gmail.com

Course Outline

ENVIRONMENT FOR VLSI TECHNOLOGY **(03 Hours)**

Clean Room And Safety Requirements, Wafer Cleaning Processes And Wet Chemical Etching Techniques

IMPURITY INCORPORATION **(05 Hours)**

Solid State Diffusion Modeling And Technology, Ion Implantation Modeling, Technology And Damage Annealing, Characterization Of Impurity Profiles

OXIDATION **(08 Hours)**

Kinetics of Silicon Dioxide Growth Both for Thick, Thin And Ultra thin Films. Oxidation Technologies In VLSI And ULSI, Characterization Of Oxide Films, High K And Low K Dielectrics For ULSI

LITHOGRAPHY **(04 Hours)**

Photolithography, E-Beam Lithography And Newer Lithography Techniques For VLSI/ULSI, Mask Generation

CHEMICAL VAPOUR DEPOSITION TECHNIQUES **(07 Hours)**

CVD Techniques For Deposition Of Polysilicon, Silicon Dioxide, Silicon Nitride And Metal Films, Epitaxial Growth Of Silicon, Modeling And Technology

METAL FILM DEPOSITION **(05 Hours)**

Evaporation And Sputtering Techniques, Failure Mechanisms In Metal Interconnects, Multi-Level Metallization Schemes

PLASMA AND RAPID THERMAL PROCESSING **(06 Hours)**

PECVD, Plasma Etching And RIE Techniques, RTP Techniques For Annealing, Growth And Deposition Of Various Films For Use In ULSI

PROCESS INTEGRATION **(04 Hours)**

NMOS, CMOS And Bipolar Circuits, Advanced MOS Technologies

(Total Contact Time:42 Hours)

Course Text and Materials

BOOKS RECOMMENDED

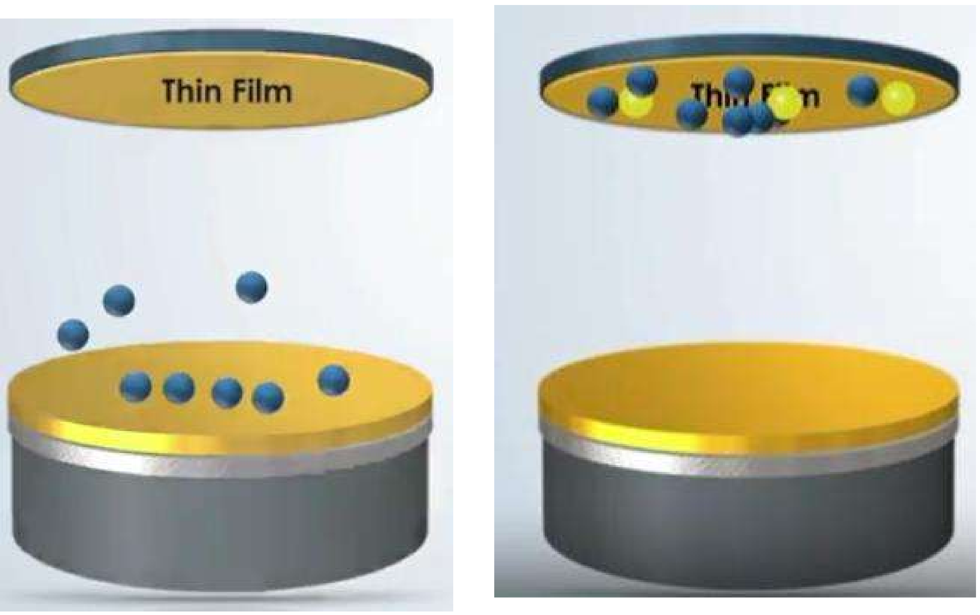
1. Chang C.Y. and Sze S. M.,"VLSI Technology",McGraw Hill,1996
2. Ghandhi S. K.,"VLSI Fabrication Principles",John Wiley Inc.,New York,1983
3. Sze S. M.,"VLSI Technology",McGraw Hill,2nd Edition,1988
4. Stephen A. Campbell,"The Science & Engineering of Microelectronics Fabrication", Oxford University Press,2nd Edition,2001
5. Peter Van Zant,"Microchip Fabrication: A Practical Guide To Semiconductor Processing", McGraw-Hill,4th Edition,2000

Additional:

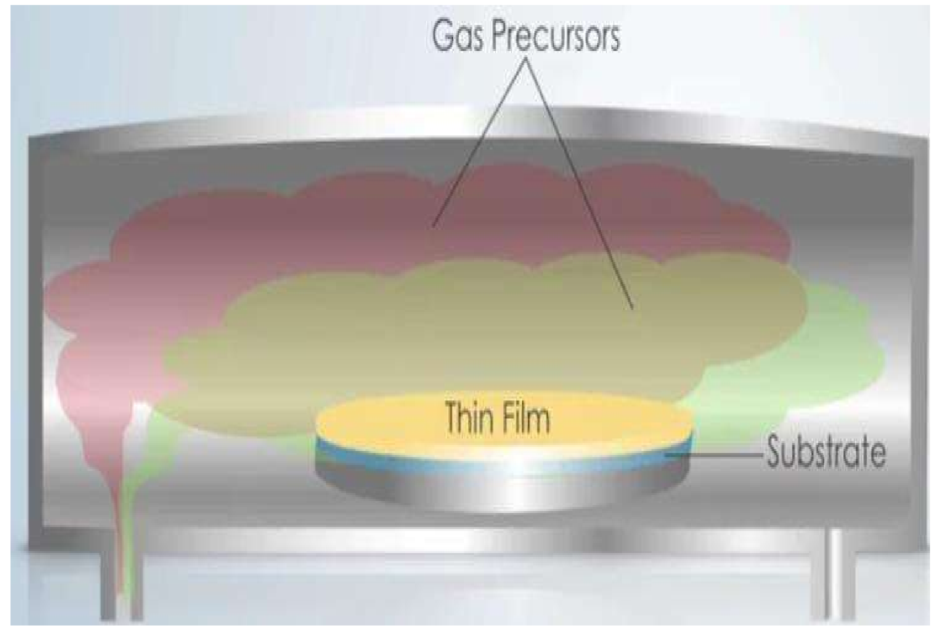
- Relevant Journals and Conferences
- Materials and Sources shared in the lectures

Physical/Chemical Vapor Deposition

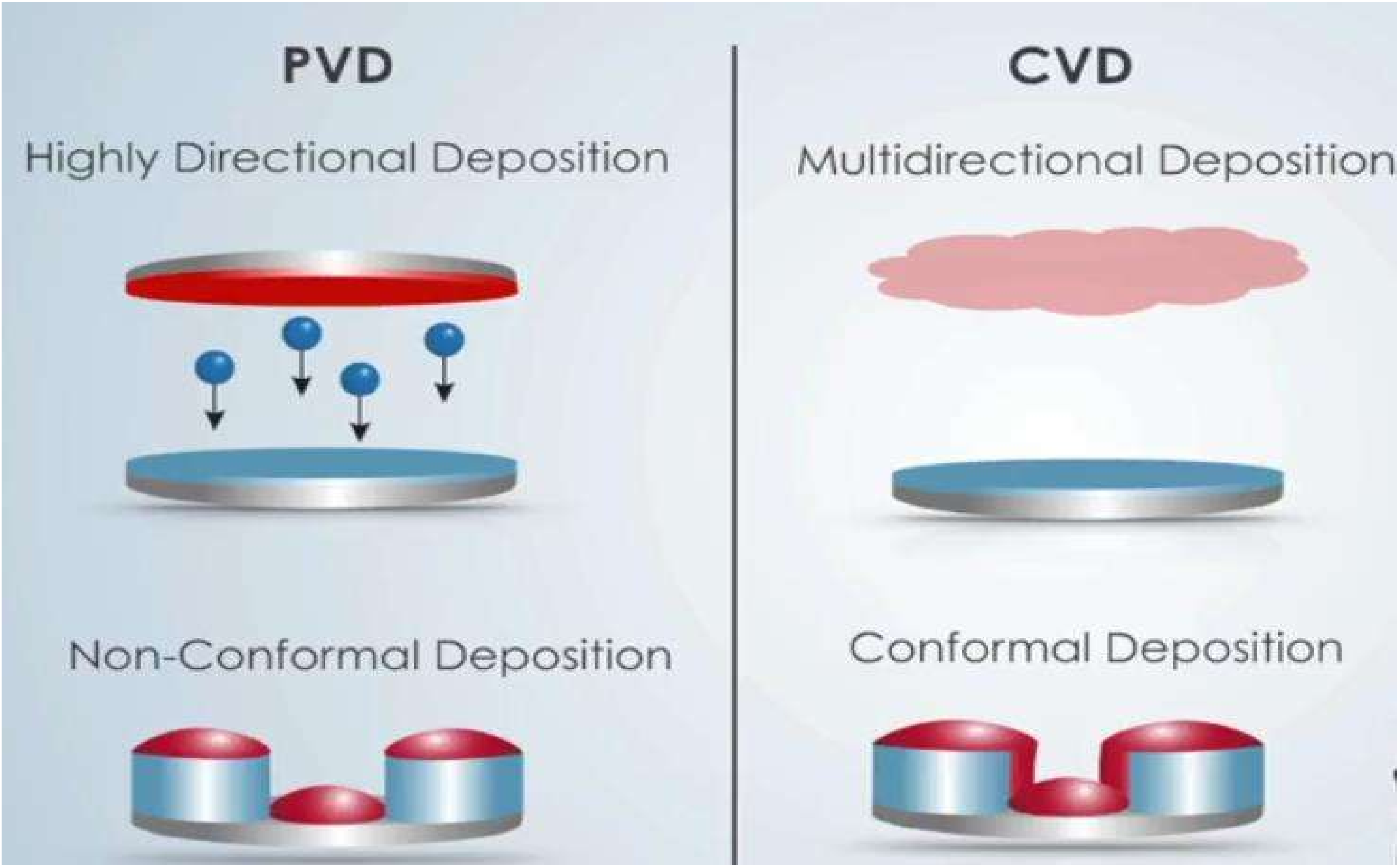
PVD



CVD

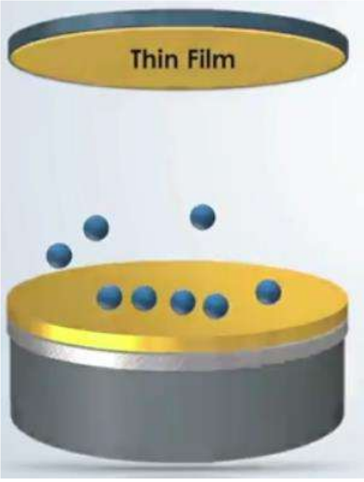


Chemical Vapor Deposition



Physical Vapor Deposition

Physical vapor deposition (PVD) refers to a family of processes in which a material is converted to its vapor phase in a vacuum chamber and condensed onto a substrate surface as a ***thin film***.

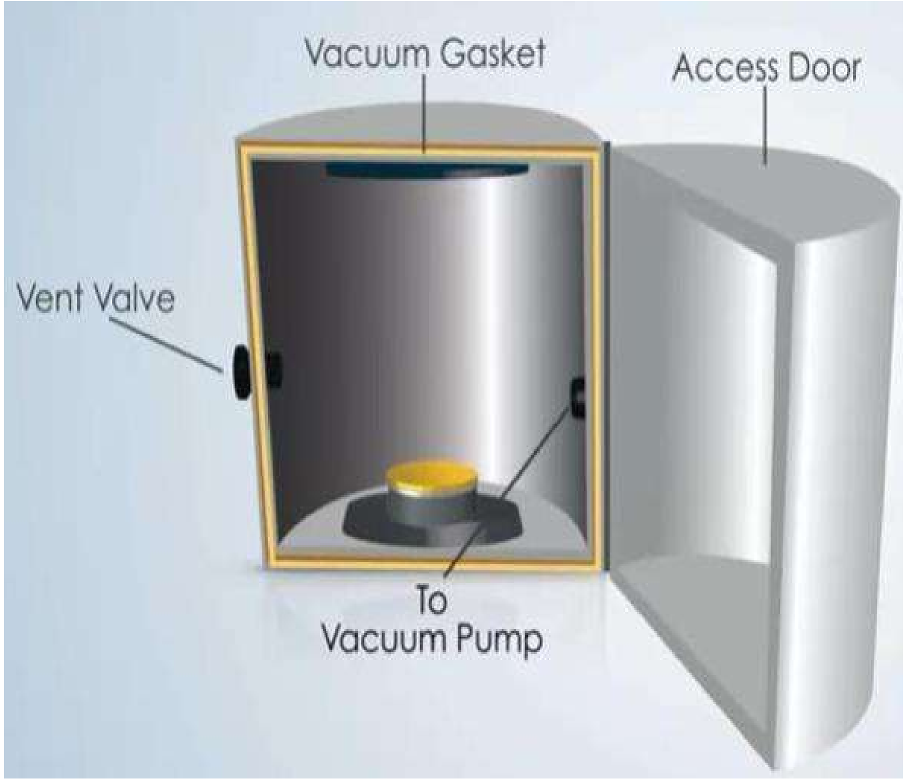


PVD can be used to produce coatings of a wide variety of materials:

- metals — alloys
- ceramics — glasses
- semiconductors — polymers

Physical Vapor Deposition

- All PVD processes consist of the following steps:
  - synthesis of coating vapor,
  - vapor transport to the substrate,
  - condensation of vapors onto the substrate surface to form a thin film.
- These steps are carried out inside a vacuum chamber, so evacuation of the chamber always precedes the PVD process.

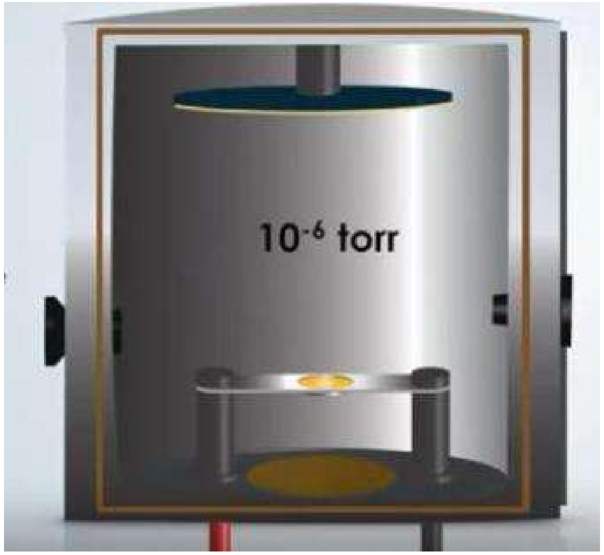


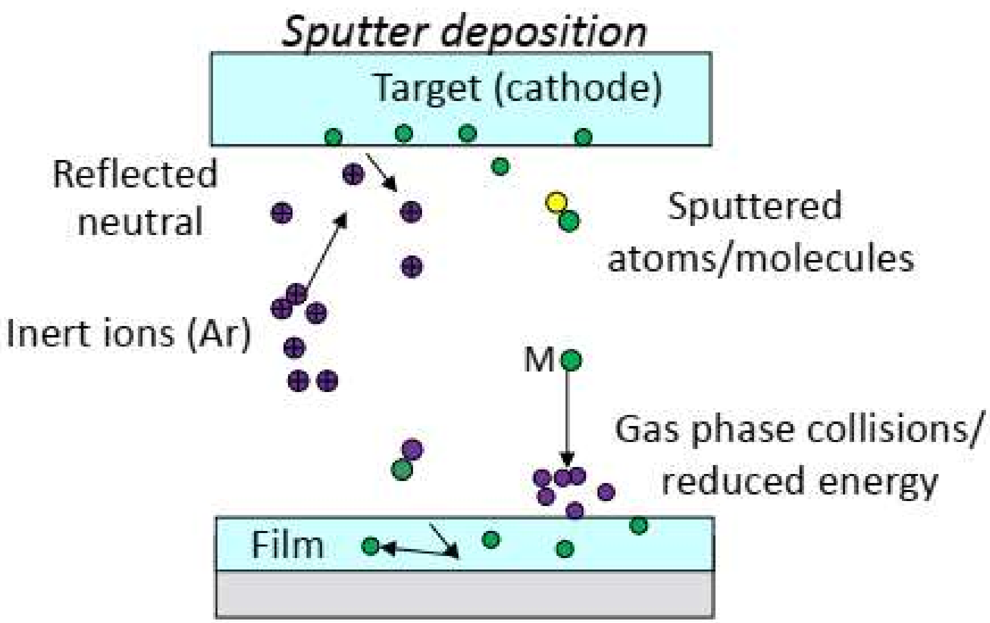
Thin Film Deposition

- Physical processes
  - Evaporation: Thermal, E-beam, Laser, Ion-plating.
  - Sputtering: DC, RF, Magnetron, Reactive.
  - Spray: Flame, Plasma.
- Chemical processes
  - Chemical Vapor Deposition (CVD): Thermal, MOCVD, PECVD.
  - Plating: Electroplating, Electroless.
  - Solgel
  - ALE
- Molecular Beam Epitaxy

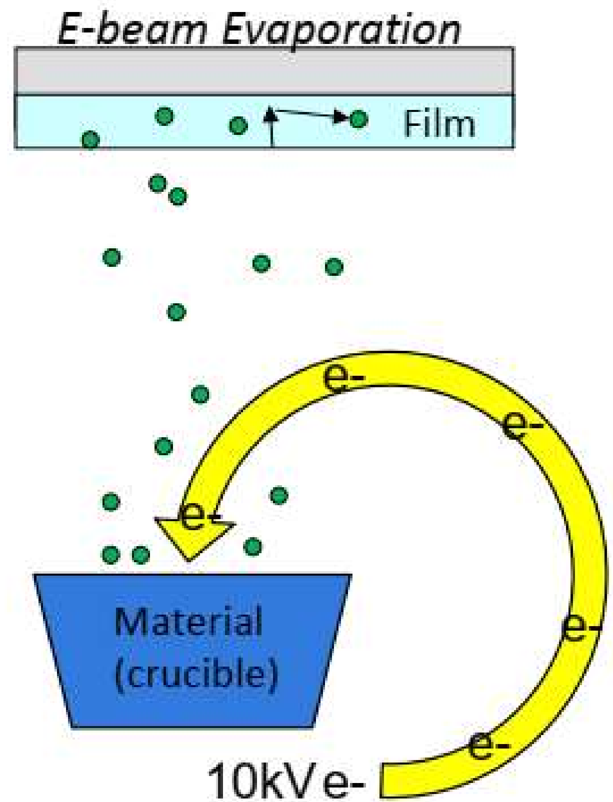
Physical Vapor Deposition

- The two most common PVD processes are:
  - **Evaporation: Thermal, e-beam**
  - **Sputtering**
- For ***evaporation***, the background pressure in the vacuum chamber is typically ~10^{-6} Torr (~10^{-4} Pa) or lower.
- For ***sputtering***, the background pressure in the vacuum chamber is typically 10^{-3} to 10^{-2} Torr (~1 Pa).





- Target material removed by kinetic energy of inert ions
- Requires plasma ignition for ionization of sputter gas (Ar)
- Good control over film properties (pressure, power, biasing, temperature)

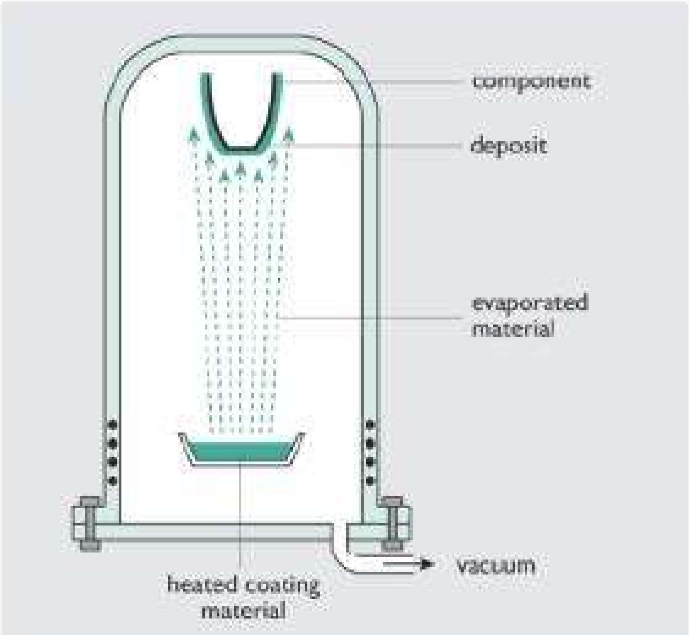


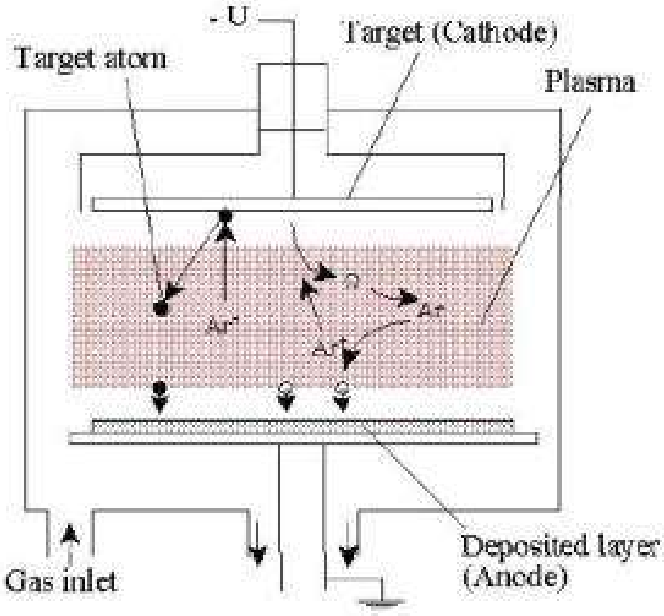
- Target material vaporized by thermal energy from electron beam
- Terrific rate control with feedback from QCM
- Can deposit at extremely slow rates (ppm level composition control)

Physical Vapor Deposition (PVD): Material is removed from a target and deposited on to a substrate

Several different methods: Sputtering, Evaporation, Laser Ablation, etc.

a. Sputtering – Use of Plasma and Ion Acceleration to remove material ("sputter") from target then deposit on substrate.
b. Evaporation – Condensation of metal vapor in high vacuum on a substrate
c. Can also do reactive deposition



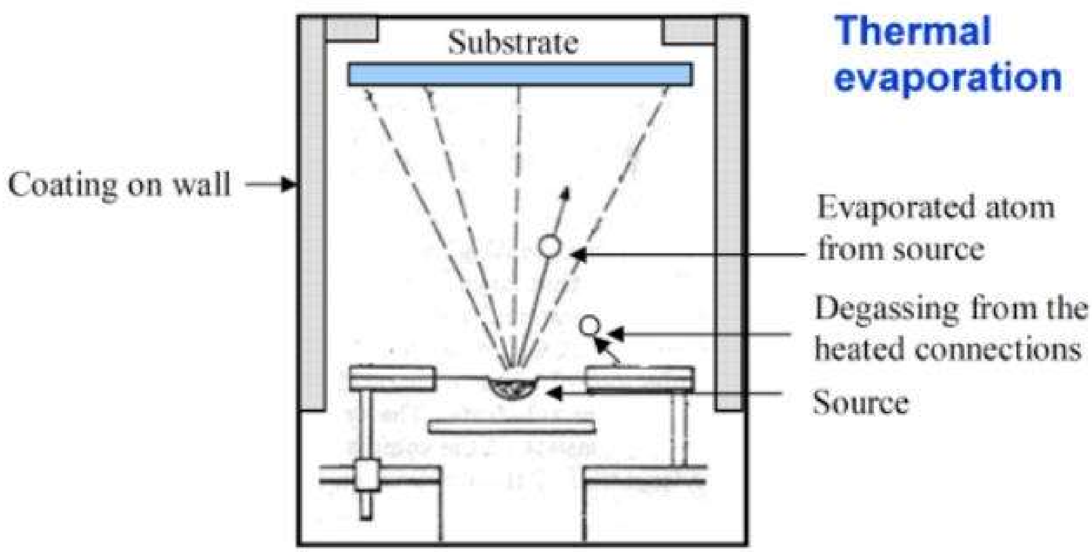


Evaporation

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

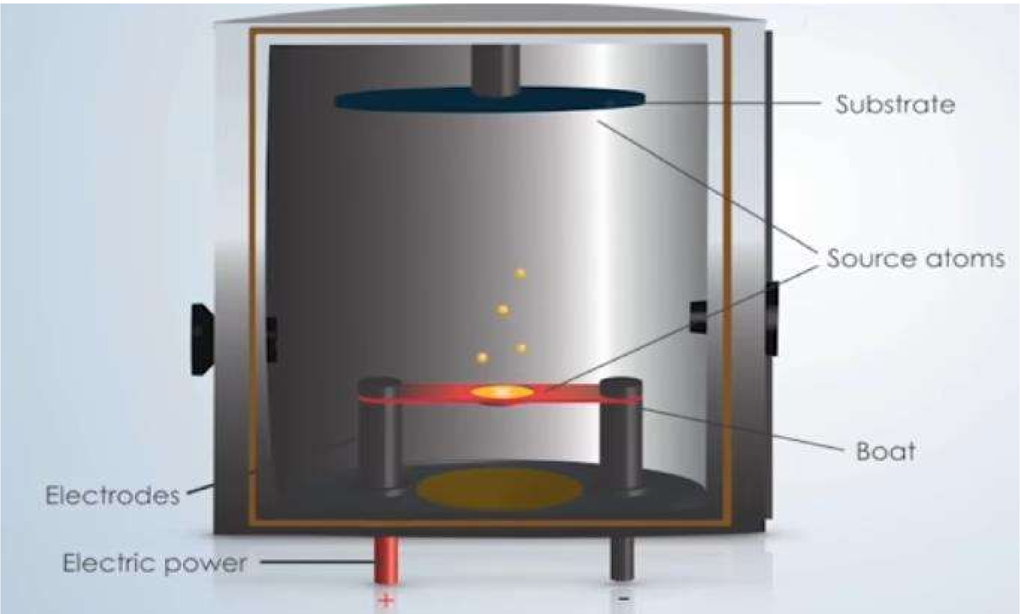
Physical Vapor Deposition

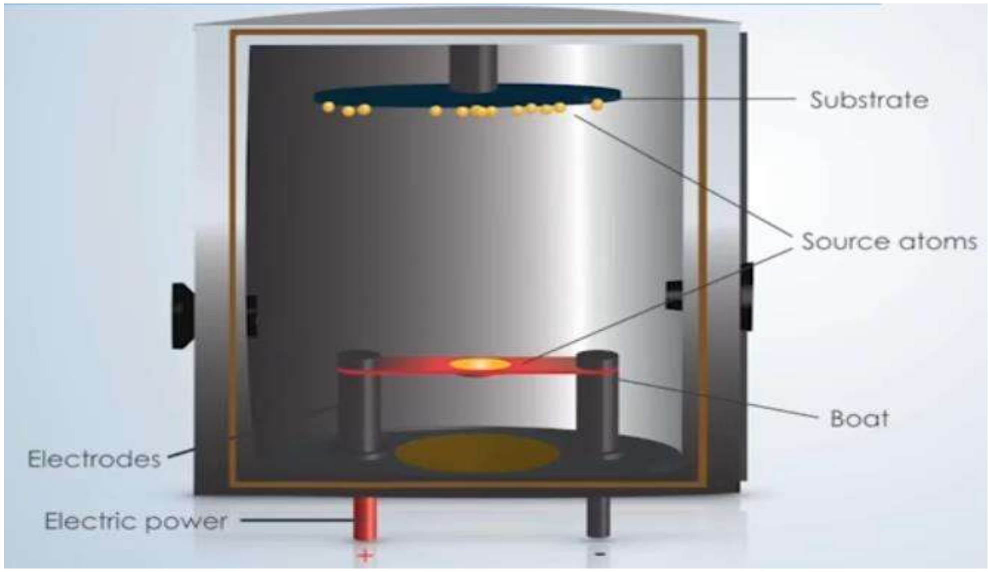
Thermal Evaporation

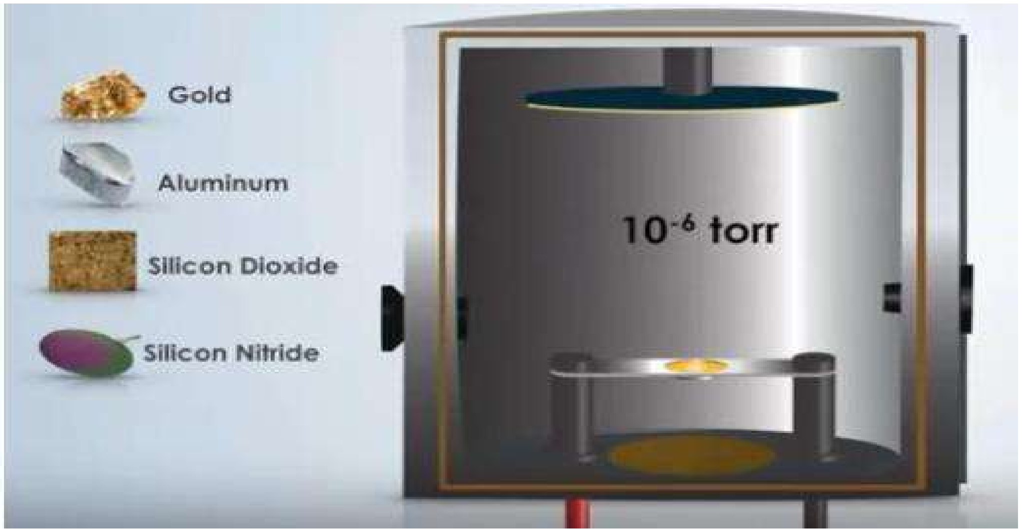


– Difficult: High melting point materials, uniformly heating, rapidly change of deposition rate, reactions between the source and the heating container.

Thermal Evaporation







Thermal Evaporation

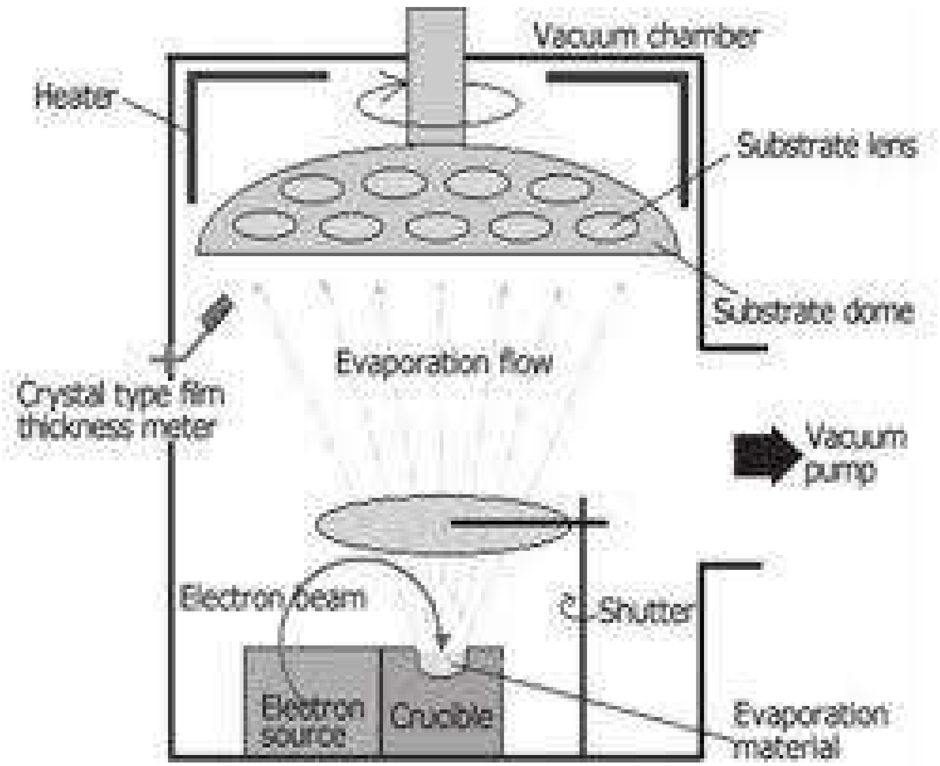
Temperature

Metal	Fahrenheit	Celsius
Aluminum (Al)	1,221°F	660°C
Gold (Au)	1,948°F	1,064°C
Copper (Cu)	1,984°F	1,085°C
Nickel (Ni)	2,651°F	1,455°C
Platinum (Pt)	3,215°F	1,768°C
Tungsten (W)	**6,191°F**	**3,422°C**

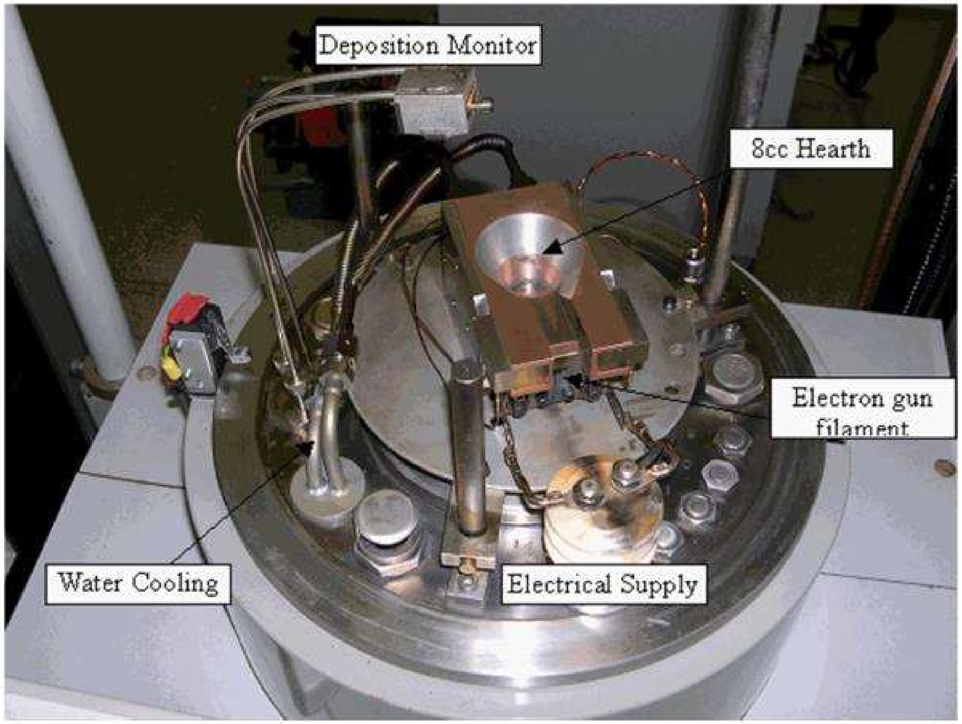
Physical Vapor Deposition

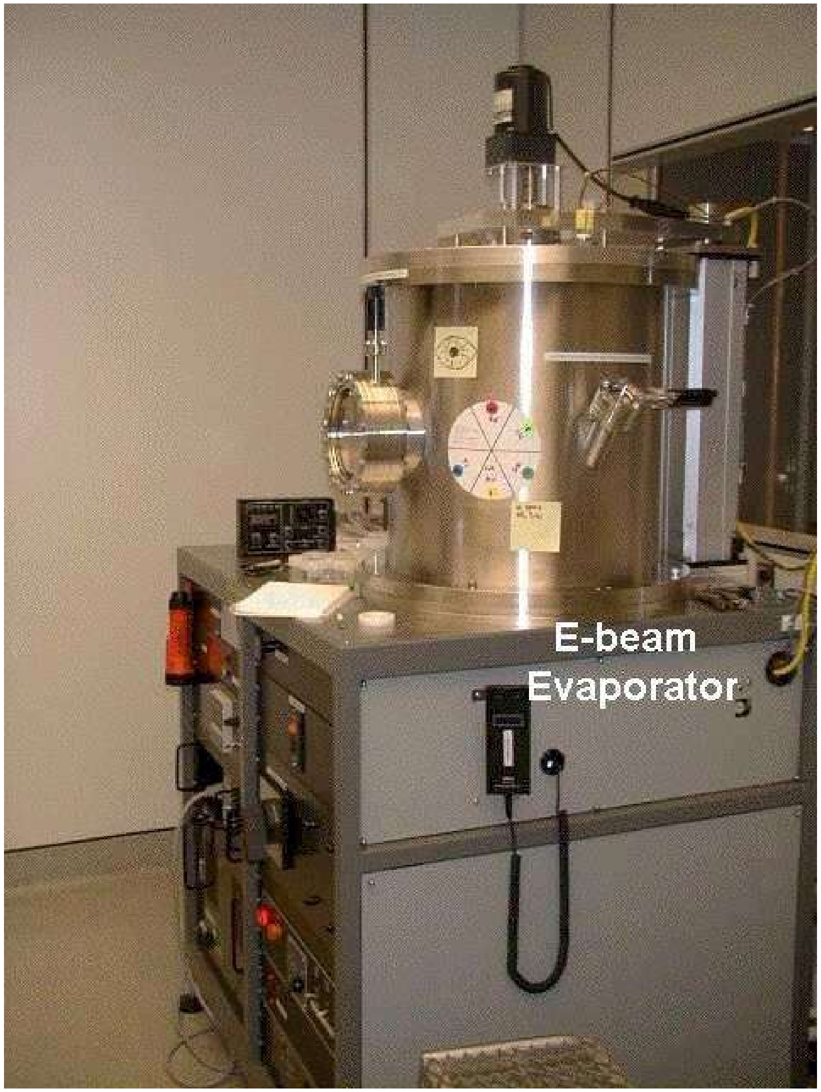
- In ***electron-beam (e-beam) evaporation*** systems, a high intensity beam of electrons, with energy up to 15 keV, is focused on the source material.
- Electron bombardment heats the source material to the temperature required for evaporation.
- Heating can be restricted to the source material itself . ⇒ The surroundings stay cool.
- Because pressure is so low in the vacuum chamber, in evaporation the source material travels in a straight line from the source to the substrate ⇒ ***shadowing***

- Focused beam of electrons are used to locally heat the Source
- Can be used to heat / evaporate even high melting point materials
- Alloys could be deposited without dissociation of constituent elements
- Ideally suited for reactive evaporation (Oxides, Nitrides etc.,)



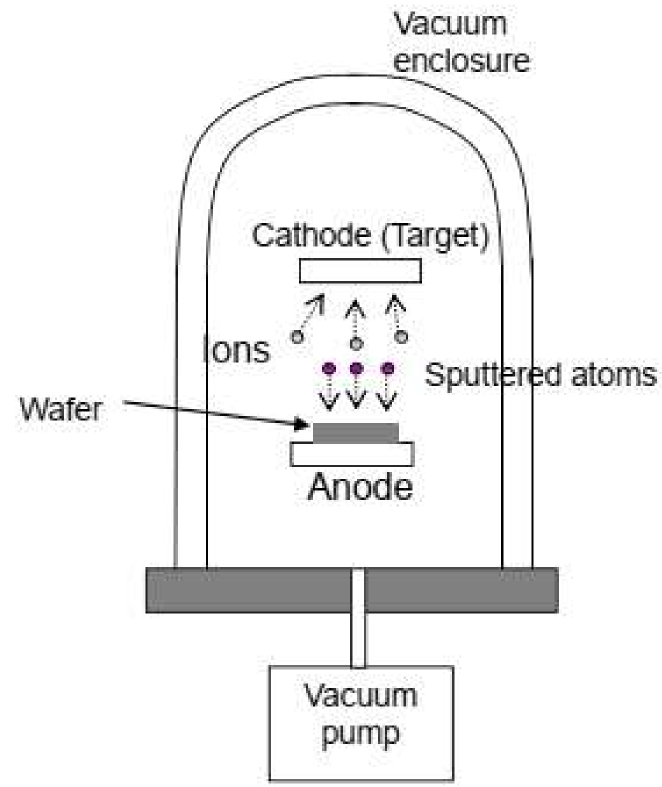
- High intensity electron beam gun (3 to 20 kev) is focused on the target material that is placed in a copper hearth (water cooled)
- The electron beam is magnetically directed onto the evaporant, which melts locally.
- No contamination from crucible.
- High quality films.
- High deposition rate 50 to 500nm/min.
- Disadvantages:
  - Process might induce x-ray damage and ion damage at the substrate.
  - At high energy(> 10kev), the incident electron beam causes x-ray emission.
  - Deposition equipment is more costly.


Deposition Monitor
8cc Hearth
Electron gun filament
Water Cooling
Electrical Supply


E-beam Evaporator

Sputtering

- **A physical phenomenon involving**
  - The creation of plasma by discharge of neutral gas such as helium
  - Acceleration of ions via a potential gradient and the bombardment of a ‘target’ or cathode
  - Through momentum transfer atoms near the surface of the target metal become volatile and are transported as vapors to a substrate
  - Film grows at the surface of the substrate via deposition



- **For ion sputtering, the source material is put on the cathode (target); for sputter deposition, the substrates to be coated on the anode.**
- **The target, at a high negative potential is bombarded with positive argon ions created in a (high density) plasma. Condensed on to substrate placed at the anode.**

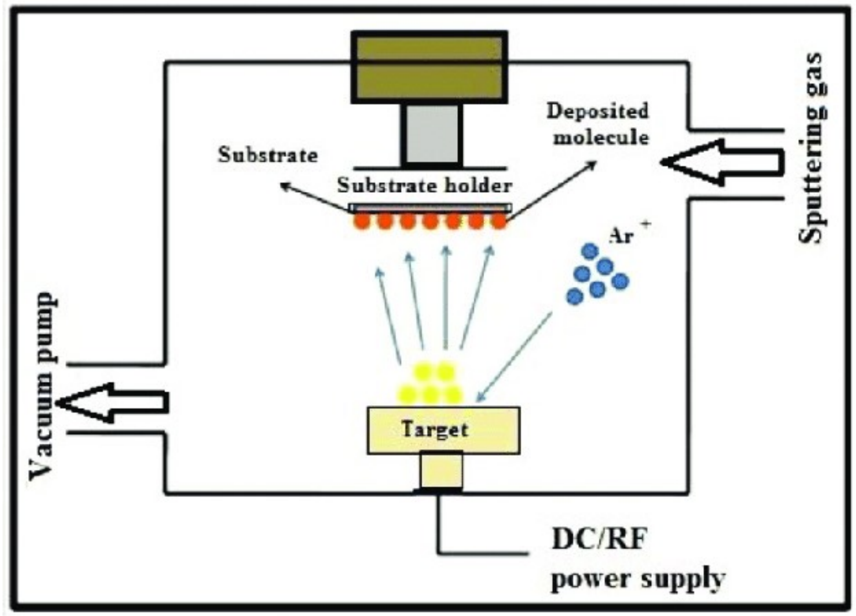
Sputtering

- Sputtering takes place after kinetic energy of the bombarding particles are much high compared to the thermal energies.
- It results in more pure and precise thin film deposition compared to evaporation.
- The number of atoms sputtered off from the target is called the **sputter yield.**
- Sputter yield can be controlled by:

  a) energy and incidence angle of ions

  b) relative mass of the ions

  c) surface binding energy of the target atom
- There are different variants of sputtering systems based on supply, sputtering mechanism.



Sputtering

Types of sputtering

a) DC/RF Diode Sputtering

b) DC/RF Magnetron Sputtering

c) Ion beam Sputtering

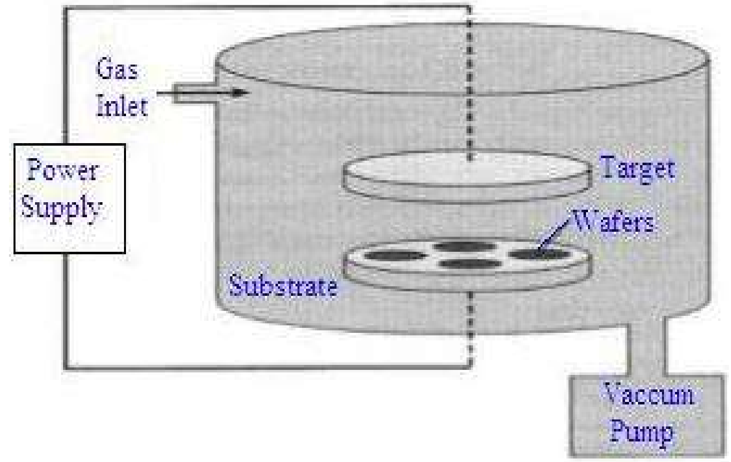
d) Pulsed DC sputtering

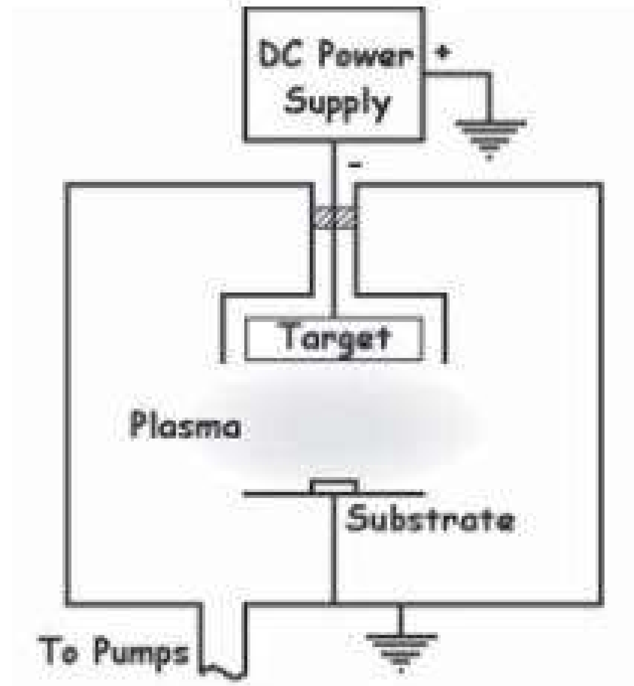
e) High Power Impulse Magnetron Sputtering (HIPIMS)

f) Co Sputtering

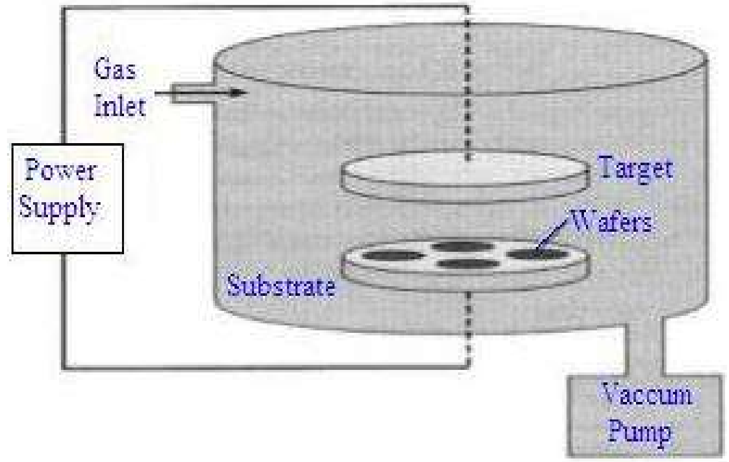
DC Diode Sputtering

- Chamber pressure is usually from 1 to 100 mTorr
- DC power is usually preferred for electrically conductive target materials as it's effective and economical.
- Target is held at negative potential and substrate/body at positive potential.
- Positive ions bombard the target and eject neutral atoms.
- In DC diode sputtering electrons are accelerated away from the target and ionize the process gases to sustain the discharge.
- To maintain the discharge optimum gas density is required.
- If the gas density is too low electrons will hit the anode without ionizing the Ar atoms.





DC Diode Sputtering



- If the gas density is too high, electrons will not gain enough energy to ionize the Ar atoms.

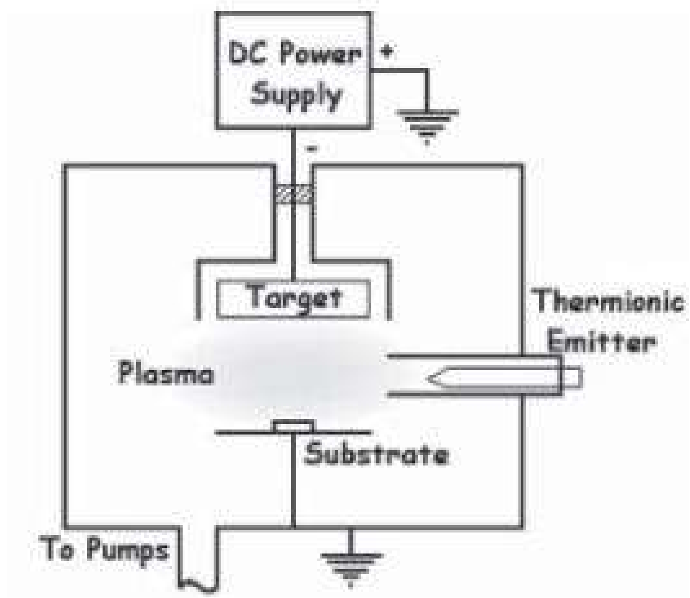
- Ar ions hitting the cathode results in secondary electrons emission.

- This interaction results in the heating of the targets, therefore cooling arrangement is required.

- **Disadvantages:**

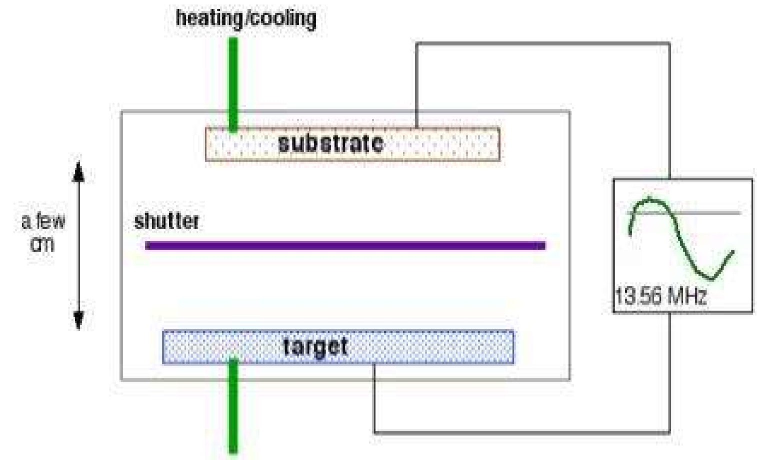
  Low deposition rates
  High discharge voltages
  Low plasma density
  High gas density

- **Triode Sputtering**

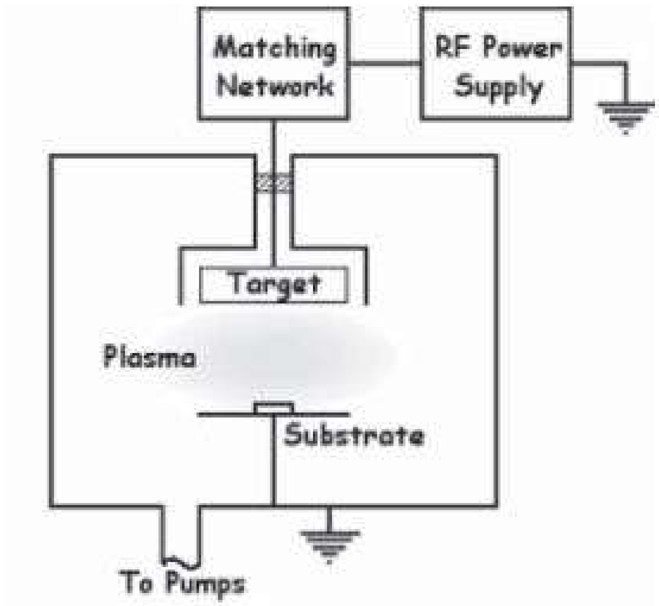


RF Sputtering

- Initially, developed to coat insulating layers.
- The power source is AC (13.6 MHz).
- RF peak to peak voltage is 1kV, electron densities are 10^9 to 10^{11} cm^{-3}, chamber pressure 0.5 to 10 mTorr.
- RF sputtering has a wider range of applications and is suitable for all the materials for conductive
- The deposition rate is lower compare with DC sputtering.
- It is used for smaller substrate sizes due to the high cost.
- Higher cost is because of the supplies and matching components.

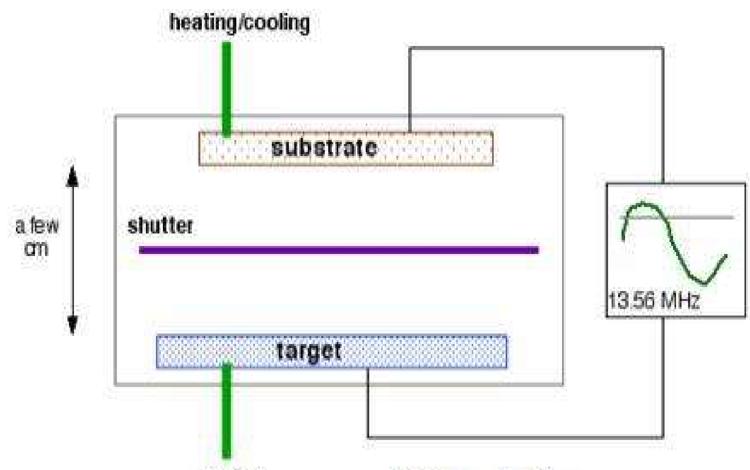


RF Sputtering Type



RF Sputtering

- The RF sputtering involves two processes. In the first cycle, the target material is negatively charged.
- This results in atoms' polarization, and the sputtering gas atoms are attracted to the source, where they knock out source atoms.
- Due to polarization, the source atoms and ionized gas ions remain on the target surface.
- In the second cycle, the target is positively charged. Due to reverse polarization, this causes the ejection of gas ions and source atoms. These ions and atoms accelerated toward the substrate to form deposition.



RF Sputtering Type

Disadvantages:

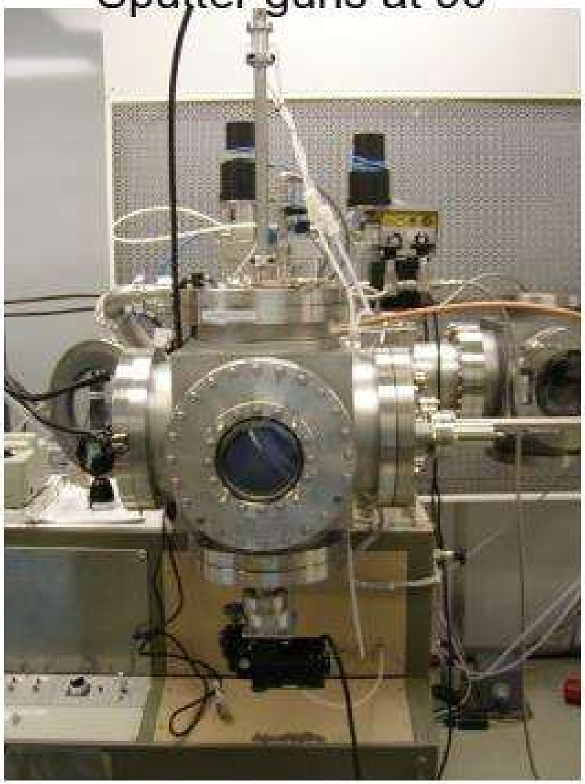
a) low deposition rates

b) High cost

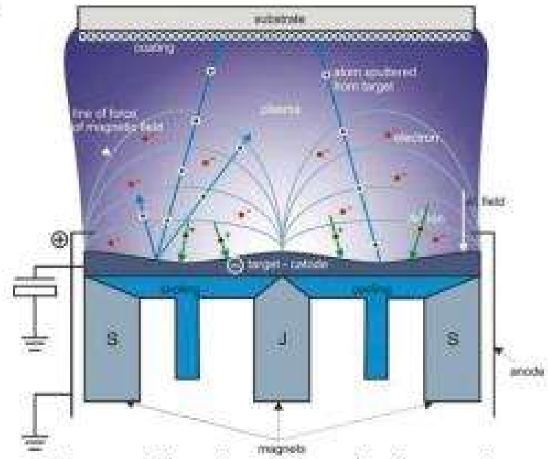
c) Non-uniform plasma

DC Magnetron Sputtering for metals
RF Magnetron for insulating materials

Sputter guns at 90°



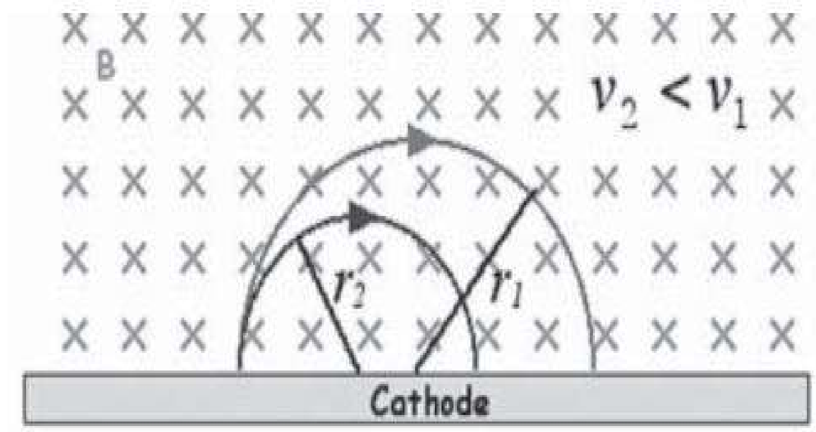
Two 2" sputter targets

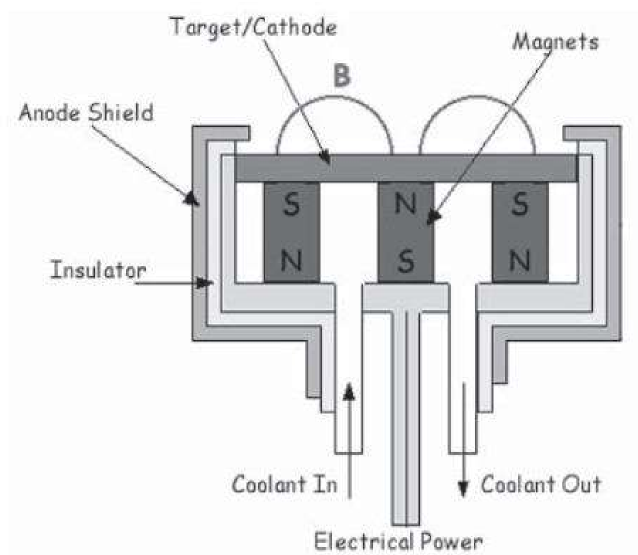


Glow discharge during dep.

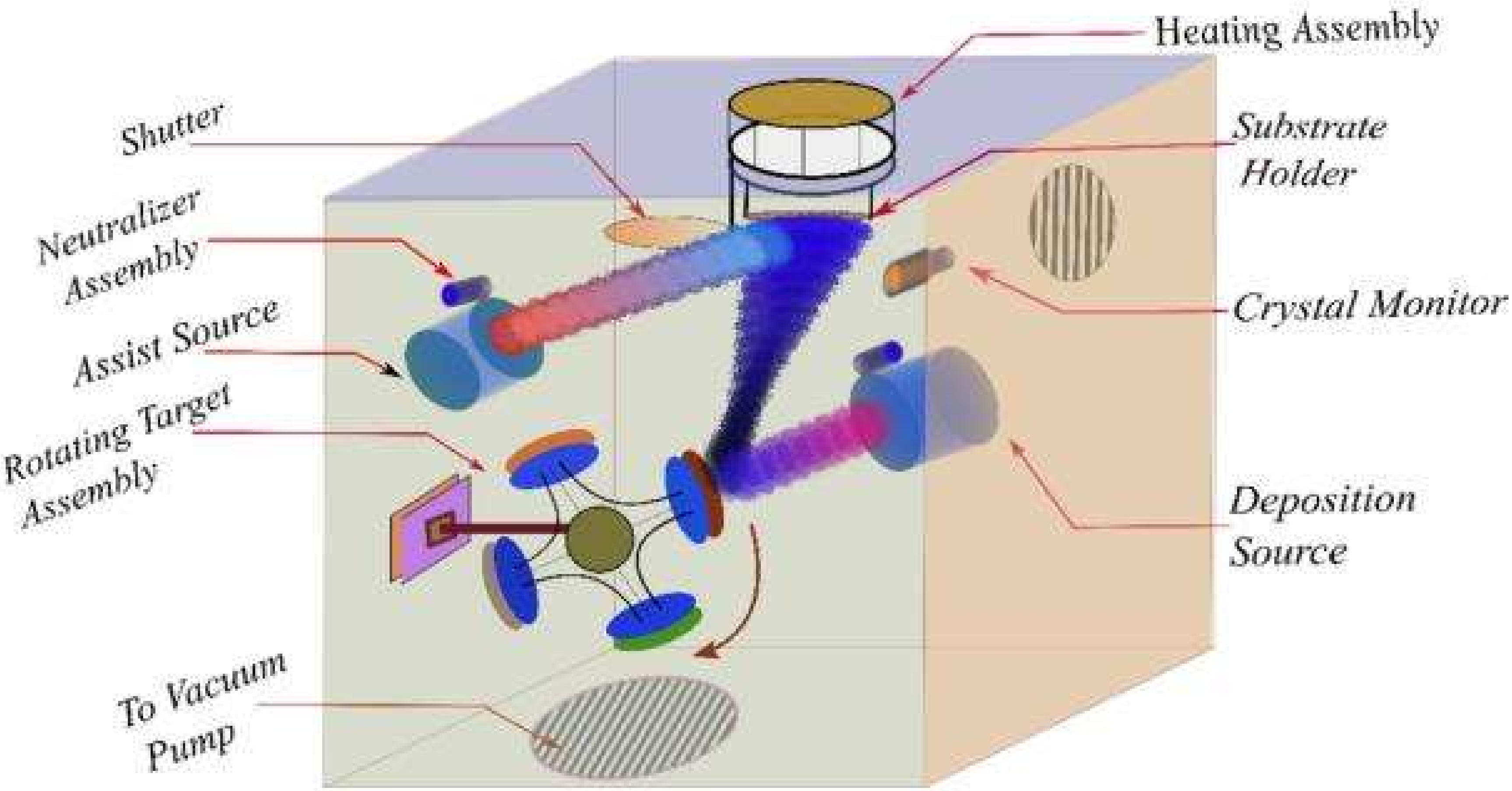
DC/RF Magnetron Sputtering

- Magnetic confinement of electrons to enhance the plasma density near the target.
- Magnetic field is added to the cathode provides E x B drift path for the electrons.
- Proper alignment of the magnetic field results in the confinement of the electrons near the surface of the target.
- The secondary electrons leaving the surface with speed v, experience the Lorentz force and begin to move in the circular path with radius r.
- It significantly increases the ion density.
- Low pressure requirements.

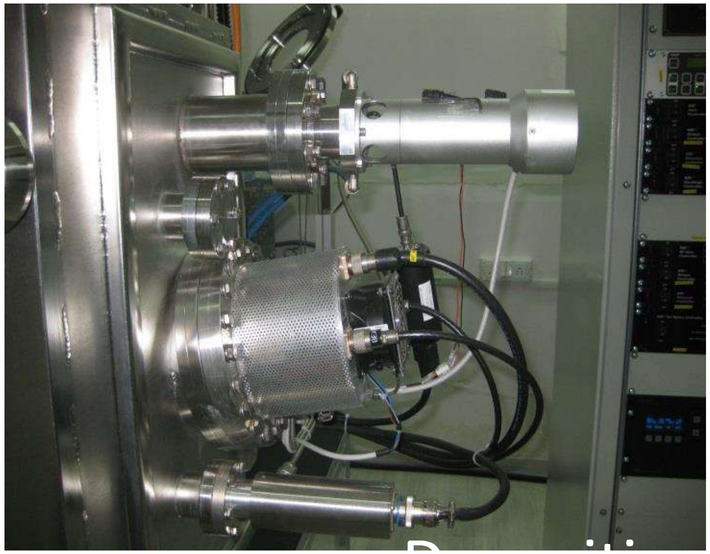


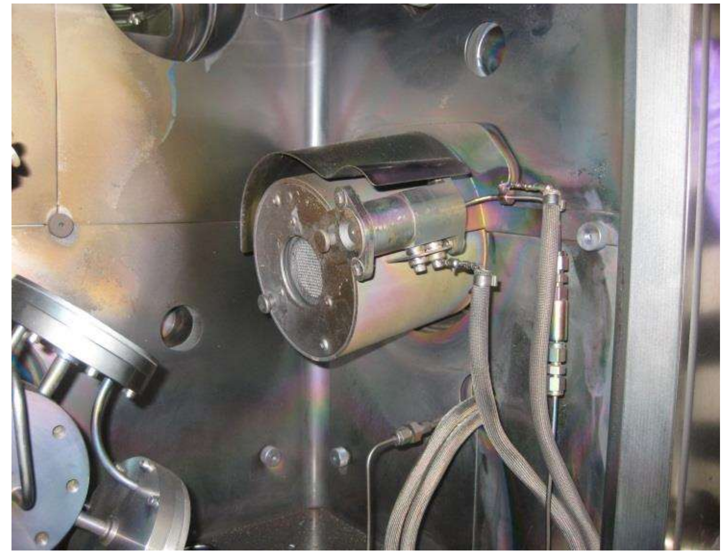


Ion Beam Sputtering

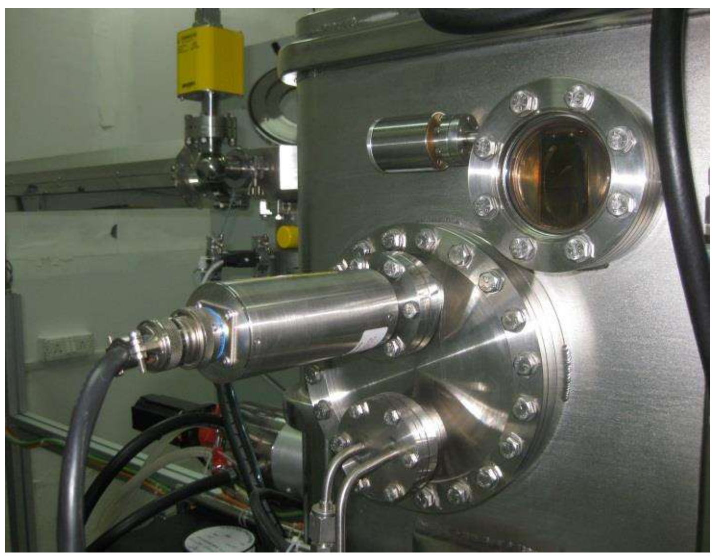


Deposition Source

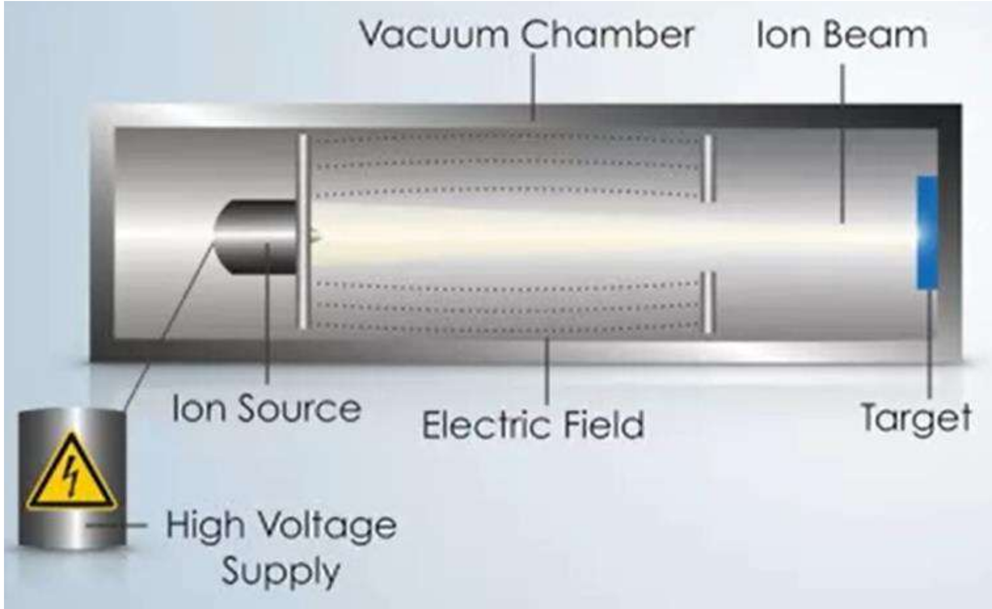




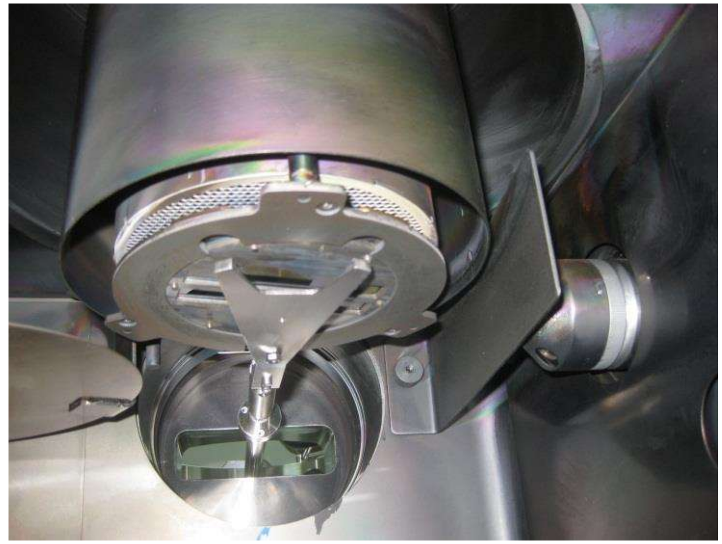
Assist Source



Ion Source



Vacuum Chamber
Ion Beam
Ion Source
Electric Field
Target
High Voltage
Supply



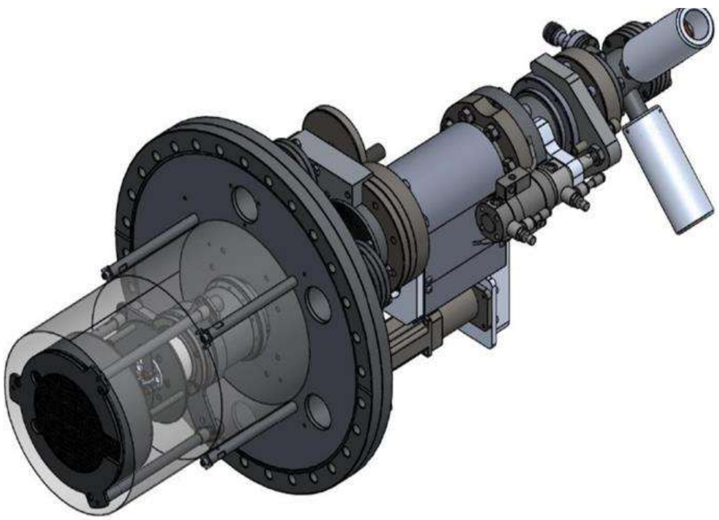
- Targets
- Sample Holder

- Vacuum Pump
- Robotic Arm


ETC 200
ETC 1800 MP
ADAPTIVE PRESSURE CONTROLLER
READY
STOP
INFICON
KRI Auto Controller
KRI Keeper Controller
KRI Emission Controller
KRI Discharge Controller
Keeper Volts
Keeper Amps
Emission Volts
Emission Amps
Discharge Volts
Discharge Amps
1.50
1.20
0.82
299
0.60


KRI RF Auto Controller
KRI Keeper Controller
KRI Emission Controller
KRI Ion Optics Controller
Beam Volts
Accel Volts
Beam mAmps
Accel mAmps
1.60
1.20
0.06
801
161
55
500

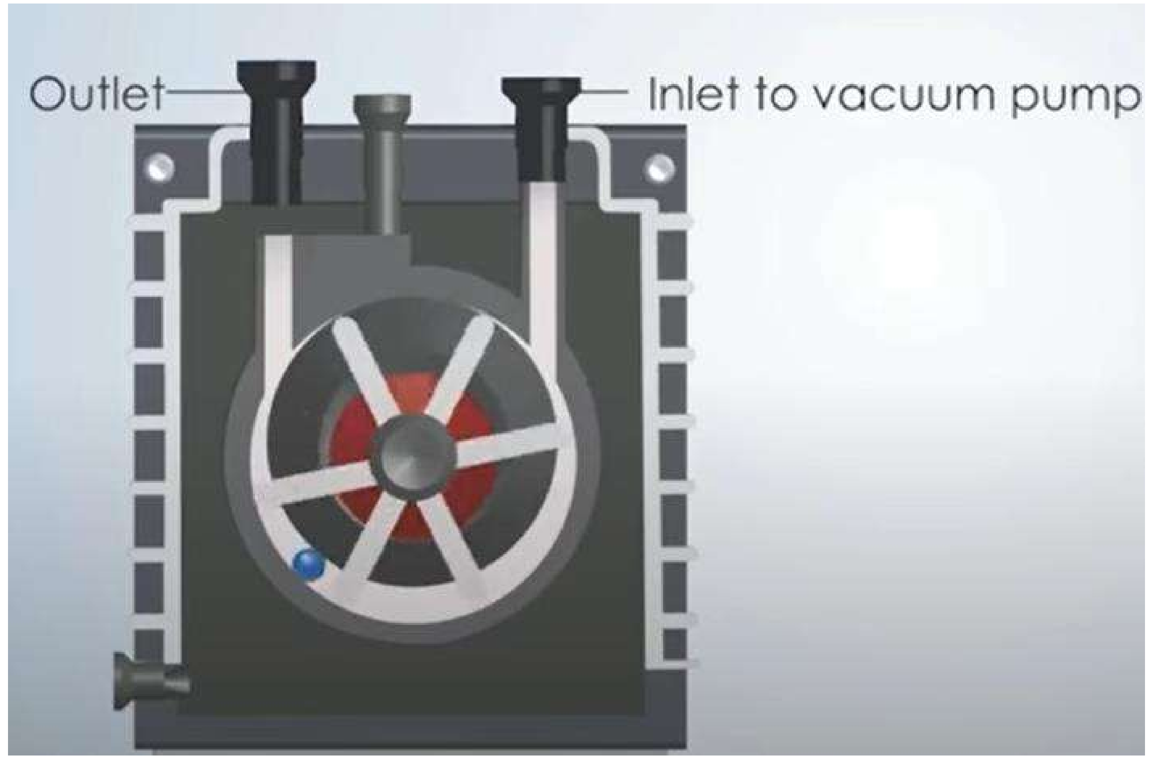

elettrorava
400 V
220 V



Pressure Gauge

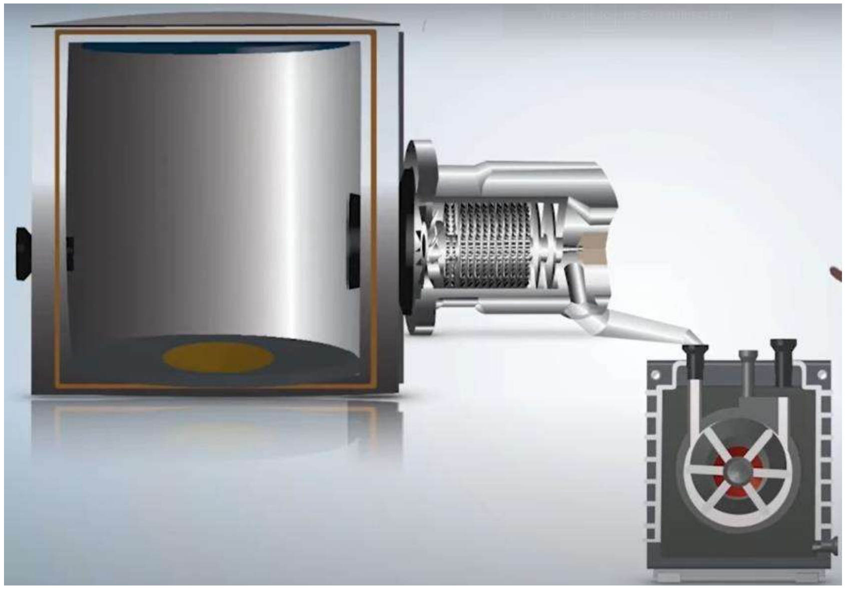
Turbo Pump

Mechanical Pumps



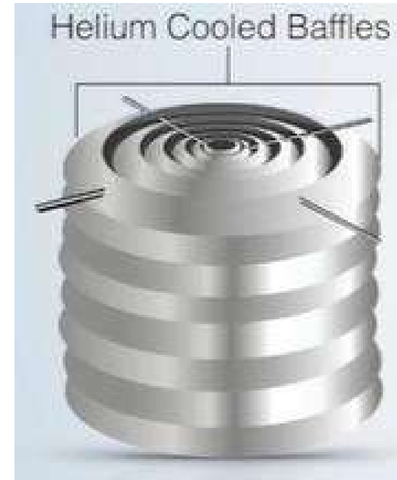
Positive Displacement
Pressure Range: 1- 0.1 Torr

Turbo Molecular Pumps



Momentum Transfer
Pressure Range: 10^{-6} to 10^{-7} Torr

Cryogenic Pumps



Entrapment or condensation
Pressure Range: 10^{-8} to 10^{-9} Torr