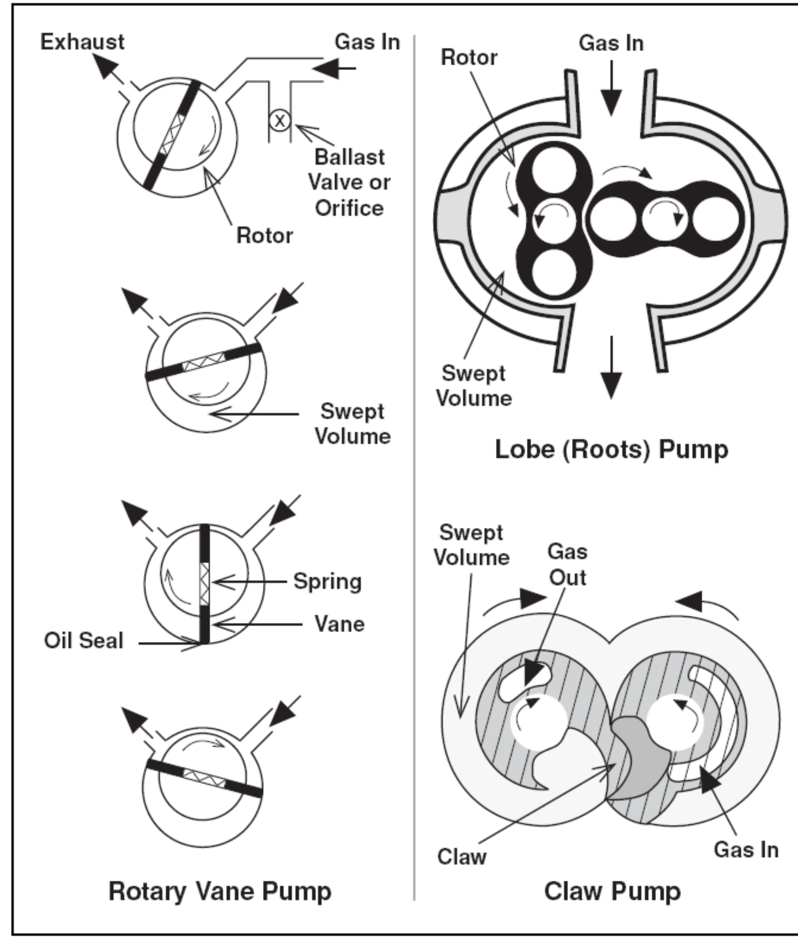
Vacuum Technology

Vacuum Pumps

- Two general classes exist:
- Gas transfer – physical removal of matter
  - Mechanical, diffusion, turbomolecular
- Adsorption – entrapment of matter
  - Cryo, sublimation, ion

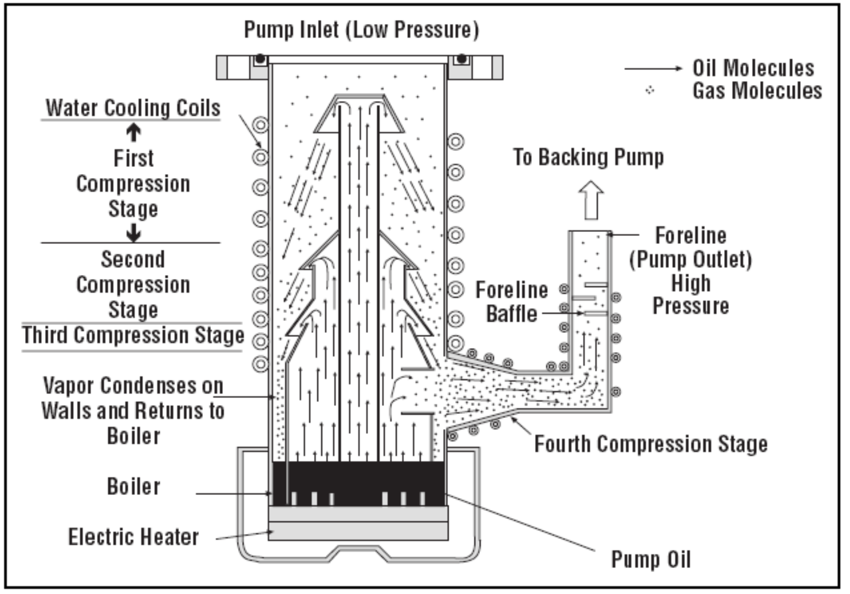
Mechanical Pumps

- High flow rates, mechanical vibrations are a problem.
- Rotary Vane Pumps
  - Spring loaded on a rotor confine, compress and discharge gas.
  - Good workhorse pump, used as fore pumps for high vacuum pumps like diffusion pumps.
  - Works from atmospheric pressure to ~ 10 mT (0.1 mT for two-stage versions)
  - Uses oil.
- Roots Pumps
  - Two figure-8 lobes rotate in opposite directions for pumping.
  - Close tolerances eliminate the need for oil.
  - Used to maintain a low vacuum (~ 1 T) in high volume LPCVD systems but can go down to 10^{-5} T with the assistance of a rotary vane pump.



Diffusion Pumps

- Si oil is boiled and vaporized in a multistage jet assembly.
- Oil vapors emerging from the nozzles impart momentum on the residual gas molecules and drive them towards the bottom of the pump.
- The molecules are compressed and exhausted.
- No vibrations.
- From 1 mT to 10^{-10} T with LN cooling (works in the molecular flow regime).
- Wide range of flow rates.
- Requires mechanical pump.
- Backstreaming of the vapors are a problem and can be minimized with cooling coils are used to condense the oil before it enters the vacuum chamber.

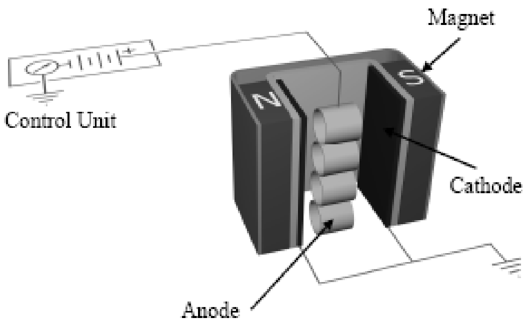


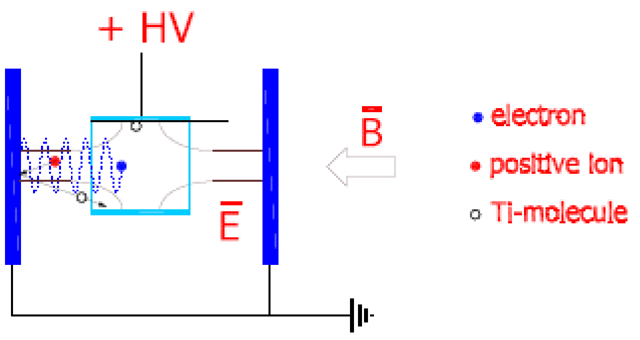
Turbo Molecular Pumps

- High rpm (20-30K) rotor blades impart momentum to molecules
- Can go from 1 mT to 10^{-10} T
- Can have vibrations
- Needs mechanical pump.
- Not good for H_2 pumping.

Ion Pumps

- A cold cathode electrical discharge creates an electron gas which is trapped by a small magnetic field.
- The electron gas ionizes residual gas particles in the chamber which are attracted to the cathode made of titanium.
- The incident ions sputter off titanium which forms a thin film on neighboring surfaces and form stable compounds with the residual gases in the chamber.
- Wide range of flow rate and pressure (still need mechanical pump)
- No moving parts or oil
- Need high voltage and magnetic fields.



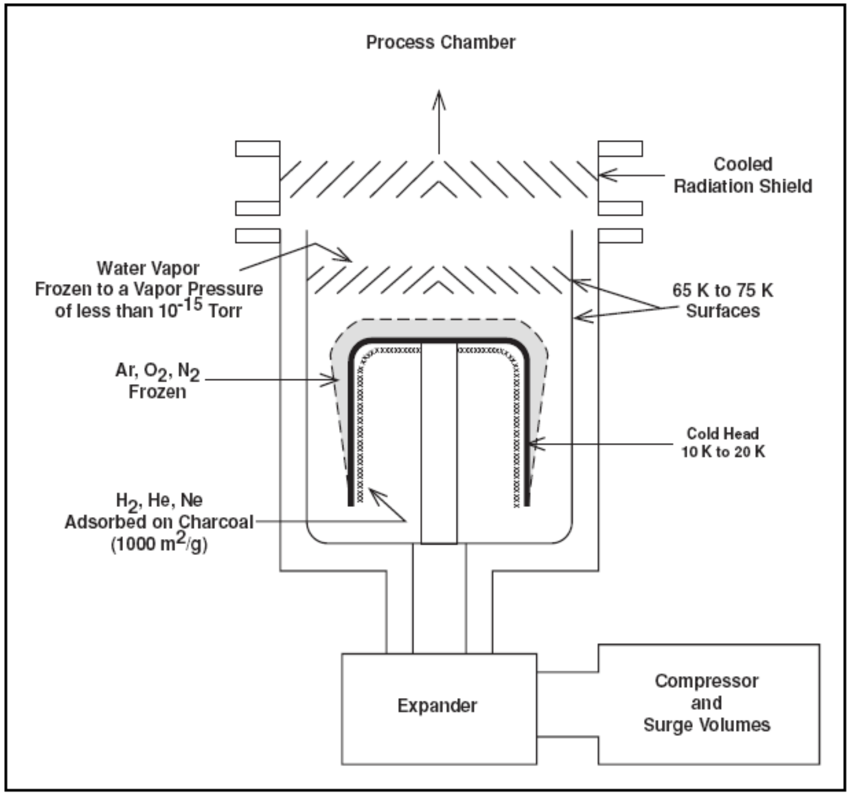


Ti Sublimation Pumps

- A freshly created Ti surface by thermal evaporation actively retains gas molecules.
- Similar advantages and disadvantages as ion pumps

Cryo Pumps

- Gases are adsorbed on cold pump walls
- Needs recharging
- Can reach UHV but needs other pump
- Coolers can cause vibrations.
- Not good for pumping H_2, He and Ne.

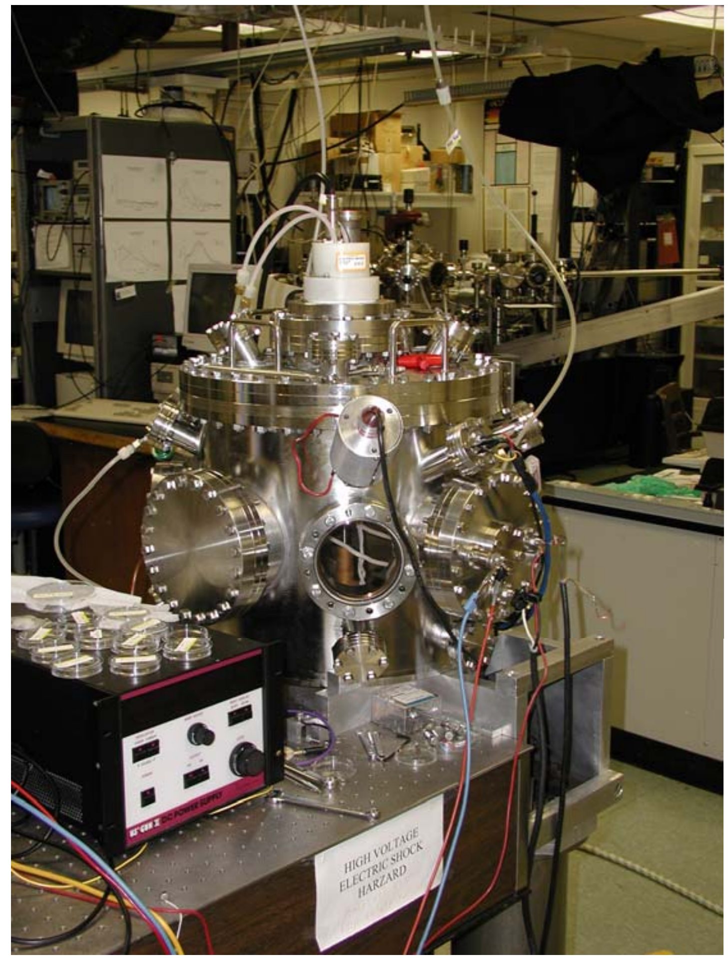


Vacuum Pumps

	Mechanical	Diffusion	Turbo molecular	Ion	Ti Sublimation	Cryo
Type	Gas Transfer	Gas Transfer	Gas Transfer	Adsorption	Adsorption	Adsorption
Range	10^{3} - 10^{-3}	10^{-3} – 10^{-7}	10^{-4} – 10^{-10}	10^{-6} – 10^{-11}	10^{-6} – 10^{-11}	10^{-6} – 10^{-9}
Pump Speed	Up to 300 lt/s	Up to 50K lt/s	50 – 3500 lt/s	Up to 1000 lt/s	Surface area dependent	Vapor dependent (~1000 lt/s)
Pros	Low vacuum workhorse, roughing pump	No vibrations	Clean	Clean, bakeable, no vibrations	Used as an addition to other UHV pumps	Clean
Cons	Vibrations, oil contamination	Hot oil	Vibrations	Lower pump speed	Not for inert gases	Vibrations, not for Helium

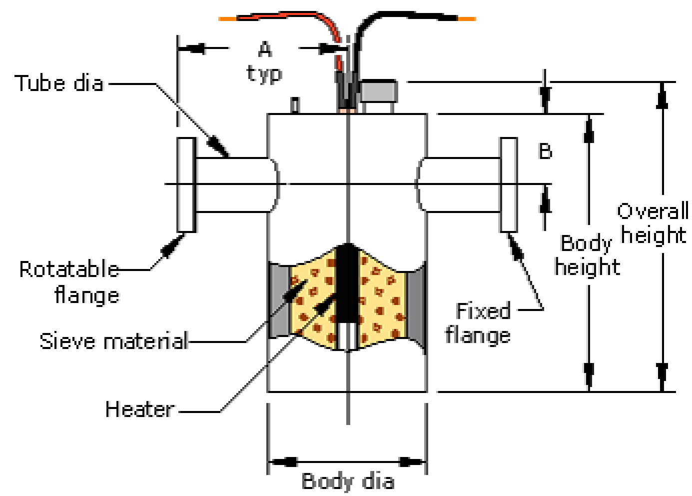
Deposition Chambers

- For standard vacuum, we can use a glass, Pyrex or stainless steel chamber.
  - Use it for CVD, sputtering and vapor deposition.
  - Mostly for lower quality, polycrystalline films
- For UHV, use a stainless steel chamber
  - Use it in MBE, CVD, sputtering
  - High quality, epitaxial films
  - Can be “baked”.



Foreline Traps

- Used to prevent hydrocarbons and water vapor from backstreaming.
- In a molecular sieve trap, a zeolite sieve acts as the trap.
- Water vapor can be baked out but trapped oil cannot. The sieve needs to be replaced periodically.
- Other types are coaxial and liquid nitrogen traps.



Vacuum Flanges

- Used to connect vacuum chambers, tubing and vacuum pumps to each other.
- Quick release flanges (QF, KF, LF)
  - up to 10^{-8} Torr, 150 °C
  - Flanges are connected by an elastometer ring and held together by a ring clamp.
- Con-Flat flanges
  - Knife edged rims inside create grooves on the gasket for the seal.
  - up to 10^{-13} Torr, 450 °C
  - Can use viton or copper gaskets

Vacuum Gaskets

- Viton Fluoroelastomer Rubber
  - Multiple uses
  - Oil resistant
- OFHC Copper
  - Single use
  - Use with CF flanges
  - Best solution for UHV

Vacuum Valves

- Used for:
  - Isolation
  - Flow control
  - Enabling access
- Valve parts:
  - Valve body
  - Flapper
  - Actuator

Valve Types

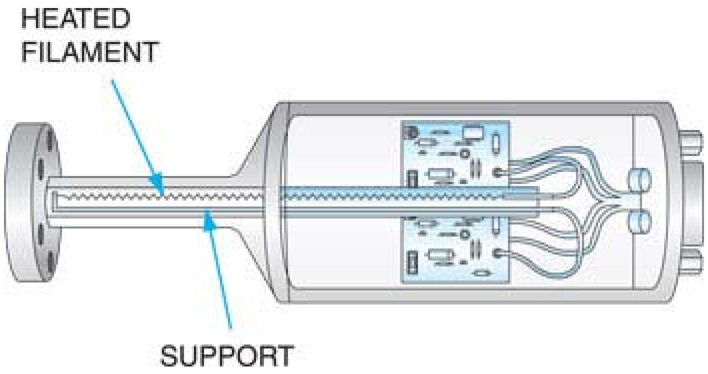
- Gate valves
  - Isolation
- Angle and inline valves
  - Pump switching, isolation
- Ball valves
  - Low vacuum, foreline trap isolation
- Butterfly valves
  - Suitable for large openings, conductance control
- Leak valves
  - Controlled gas flow

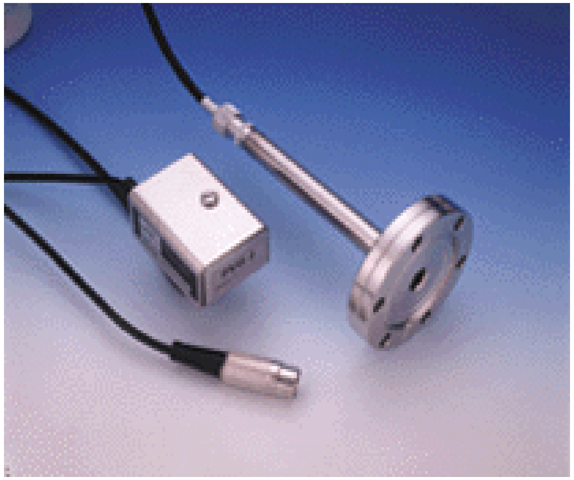
Pressure Gauges

- Absolute pressure
  - Referenced against perfect vacuum
  - 1 atm = 760 Torr = 14.7 psi
- Gauge pressure
  - Referenced against atmospheric pressure
- Differential pressure
  - Pressure difference between two points
- Different gauges measure different scales.
  - Combine various gauges in a single controller.

Pirani Gauge

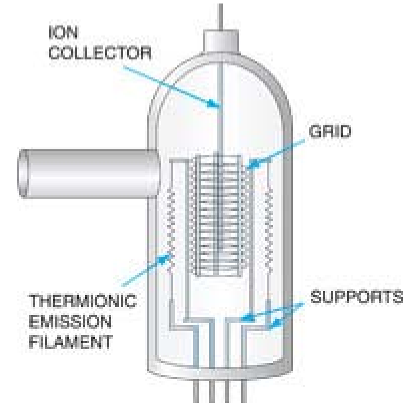
- Operation is based on thermal conductivity.
- A filament is heated and its temperature is measured.
- The temperature depends on the heat loss to the environment which in turn depends on the vacuum level.
- Will work between 10 - 10^{-3} Torr





Ion Gauge

- A filament is used to emit electrons which are attracted to a positively charged grid.
- Inside the grid is a negatively charged collector.
- The electrons collide with gas molecules around the grid and ionize them.
- The positively charged ions are attracted to the collector and create an ionic current.
- Works between $10^{-3} – 10^{-10}$ Torr

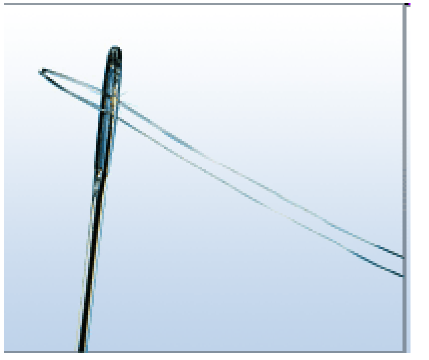


Feedthroughs

- Electrical
  - Power
  - Instrumentation
  - Thermocouple
- Optical
  - Viewports
  - Fiber optic
  - Glass-metal
- Motion
- Fluid

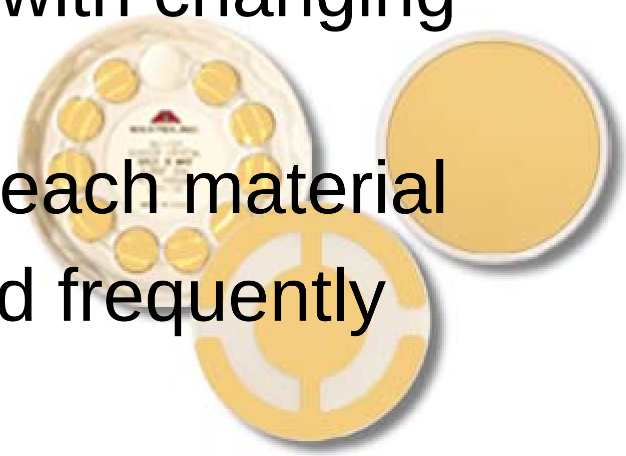
Thermocouples

- Thermal gradients will produce electrical voltage differences in conductors.
- Using two different conductors meeting at a point will generate a voltage difference that can be calibrated.
- The v vs. T relationship is non-linear and not very precise (not good around ~0.1° C)



Crystal Monitor

- Monitors thin film deposition rate and calculates thickness
- Quartz crystal has an oscillating electrical current, oscillates at a fixed frequency
- Oscillation frequency changes with changing mass
- Must input material density for each material
- Quartz crystal must be changed frequently
- Position needs to be calibrated

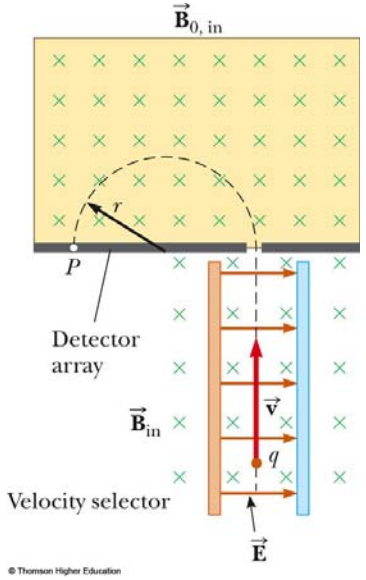


Mass Spectrometry

- Ions with a high charge to mass ratio are deflected more strongly in magnetic fields.
- Charge particles into ions.
- Accelerate them using an electric field.
- Deflect them using a magnetic field.
- Used to obtain chemical composition data.

$$\vec{\mathbf{F}} = q\vec{\mathbf{E}} + q\vec{\mathbf{v}} \times \vec{\mathbf{B}}$$

Mass Spectrometer



$$\frac{m}{q} = \frac{rB_0B}{E}$$

RHEED

- **R**eflection **H**igh-**E**nergy **E**lectron **D**iffraction
- A well formed crystal will have a well-defined diffraction pattern
- As successive layers are formed, the intensity of each spot will fluctuate.