NACK CENTER
Building College-University Partnerships for Nanotechnology Workforce Development

Vacuum Function, Operation and Systems

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Outline

- Gas properties and defining vacuum
- Vacuum pumps
- Integrated vacuum systems? At least a peak.

Why is vacuum technology important?

- Vacuum = Clean
- Vacuum also equals safe. Vacuum chambers **separate the manufacturing process from workers and the environment.** Generally vacuum processing may use small amounts of materials, so this is also **environmentally conscious**.
- Vacuum based processes are common in nanofabrication because they offer reduction in ambient contamination, the conditions are repeatable, and vacuum is necessary for many thin film processes.
- This introduction section will give you the background to use the hands on-vacuum trainer, and vacuum simulator, vacuum based process systems and some characterization tools.

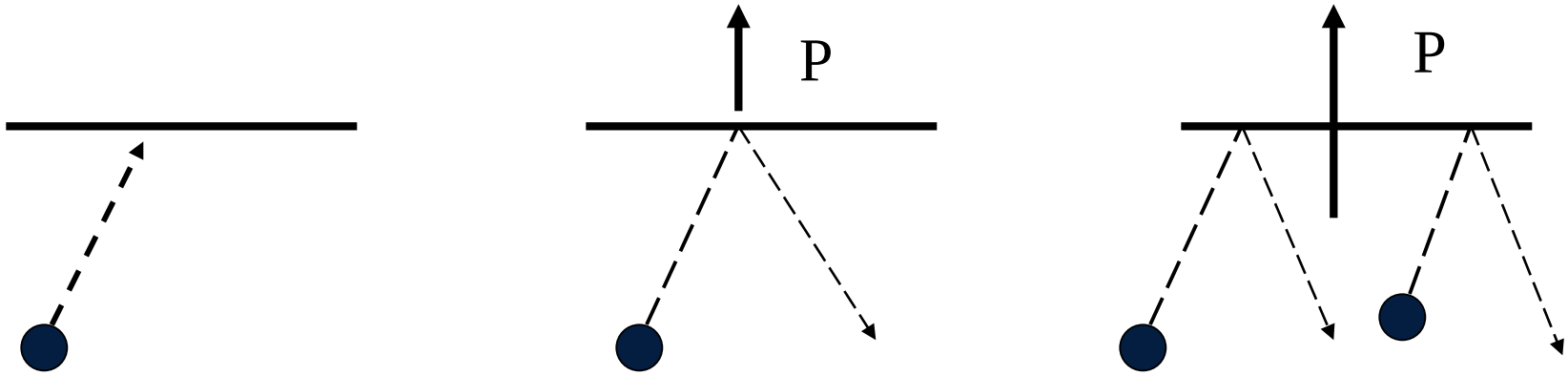
Vacuum

- The removal of gas molecules (air, moisture, and gas residues) in a closed container to achieve a pressure less than atmosphere.
- Without this fundamental concept, many common processes in modern nanofabrication would not exist. This process is not only important for processing material, but it is also vital for many characterization techniques.

Properties of Gases

- Gases of equal volume and pressure have the same number of molecules.
- Gases are compressible.
- Gases expand with increased temperature.
- Gases mix completely.
- The total pressure of a mixture of gases is the sum of the pressures of each.
- Gases fill a container completely, irrespective of pressure and shape of the container.
- Certainly these are all true given enough time to reach steady state.

Theory of Pressure



Before collision **After collision** **Multiple collisions**

- The momentum P of the atom just before striking the wall must be equal to the vector sum of the momentum P' of the rebounding atom plus the momentum P_w given to the wall.
- The continual bombardment on the wall by the gas atoms produces a steady force on the wall.

Atmospheric Pressure

- The air around us exerts a pressure on the earth's surface of 14 lbs/in^2 = 760 Torr
- This weight of air pushing on the earth's surface is referred to as atmospheric pressure.

Atmospheric Properties

- Our atmosphere is comprised of a mixture of gases.
- At sea level it consists of 78.08% Nitrogen (N_2), 20.95% Oxygen (O_2), 0.93% Argon (Ar), and very small amounts of Carbon Dioxide (CO_2), Neon (Ne), Helium (He), Krypton (Kr), Hydrogen (H_2), and Xenon (Xe). Note that water vapor is not listed, and is a very important consideration.

Vacuum Ranges

- Vacuum is typically measured in Torr (T)
  - Atmospheric pressure = 760 T
  - 1 atmosphere = 760 T
- Generally, there are three vacuum ranges:
  - Low Vacuum (Rough Vac)
  - High Vacuum
  - Ultra High Vacuum

Vacuum Ranges

Vacuum Range	Numerical Value
Rough Vacuum	Atm – 10^{-3} T
High Vacuum	10^{-6} T $\rightarrow$ 10^{-3} T
Ultra High Vacuum	$\downarrow$ 10^{-6} T

Mean Free Path (MFP)

- The average distance a gas molecule moves before it strikes another gas molecule.
- When the pressure is lowered in a vacuum, the space between the gas molecules increases.
  - This is important for plasma generation and etch profile control.
- The MFP varies according to vacuum range.

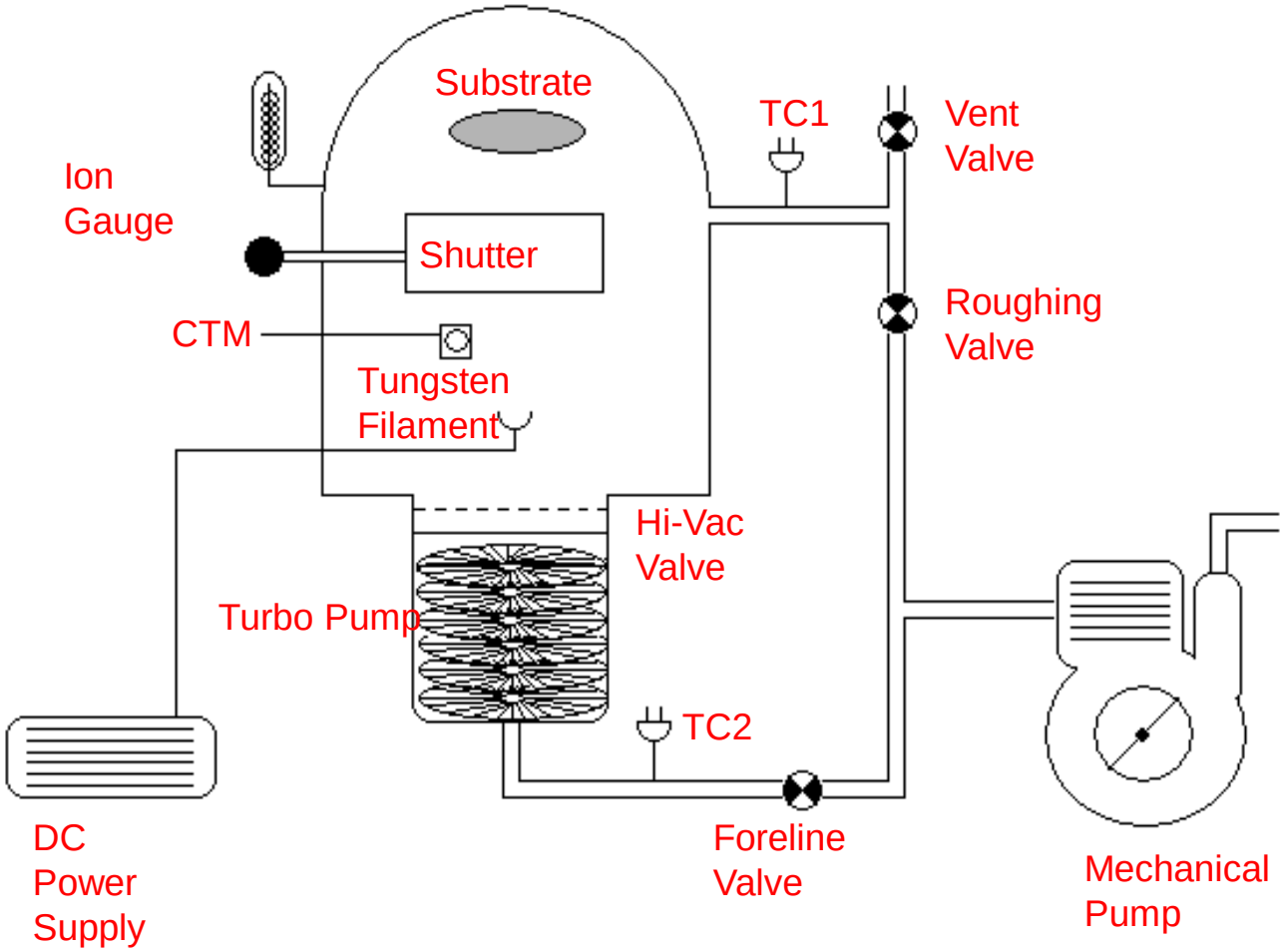
MFP and Molecular Density Versus Pressure

Pressure	760 Torr	$1x10^{-3}$ Torr	$1x10^{-9}$ Torr
# of molecules/cm^3	$3x10^{19}$	$4x10^{13}$	$4x10^{7}$
Mean Free Path	$5x10^{-6}$ cm	5 cm	48km

MFP and Molecular Density

- The previous table gives us insight for both system design and contamination issues.
- As you can see, the mean free path can establish the size of a process tool.
- The mean free path distance is also critical to understanding dissociation in plasma processing.
- So, understanding vacuum, is necessary to understand material processing and system design.
- Let's revisit the evaporator and examine the connection between design and vacuum technology.

Thermal Evaporator



System Design

Pressure	760 Torr	$1x10^{-3}$ Torr	$1x10^{-9}$ Torr
Mean Free Path	$5x10^{-6}$ cm	5 cm	48km
Film purity	Film with be highly dependent upon changing ambient conditions Junk?	Film will react with the residual air, poor quality, good enough for fishing lures maybe	Film will be very pure, probably "too pure" or expensive for most needs. Cell phone parts are generally 10-6T.

MFP and System design

- As you can see, the mean free path can establish the size of a process tool.
- The MFP is important in many applications for many reasons, but the importance is clear with the evaporator example.
- Many nanoscale products are dependent with vacuum levels typically at 10^{-6}T. This is a good estimate, and devices like lasers need deeper vacuum, but again 10^{-6}T is a pretty useful vacuum range for materials that are very pure.
- For characterization, it is also very useful for many reasons.
- Next we will look at gauges as a means to further appreciate vacuum technology

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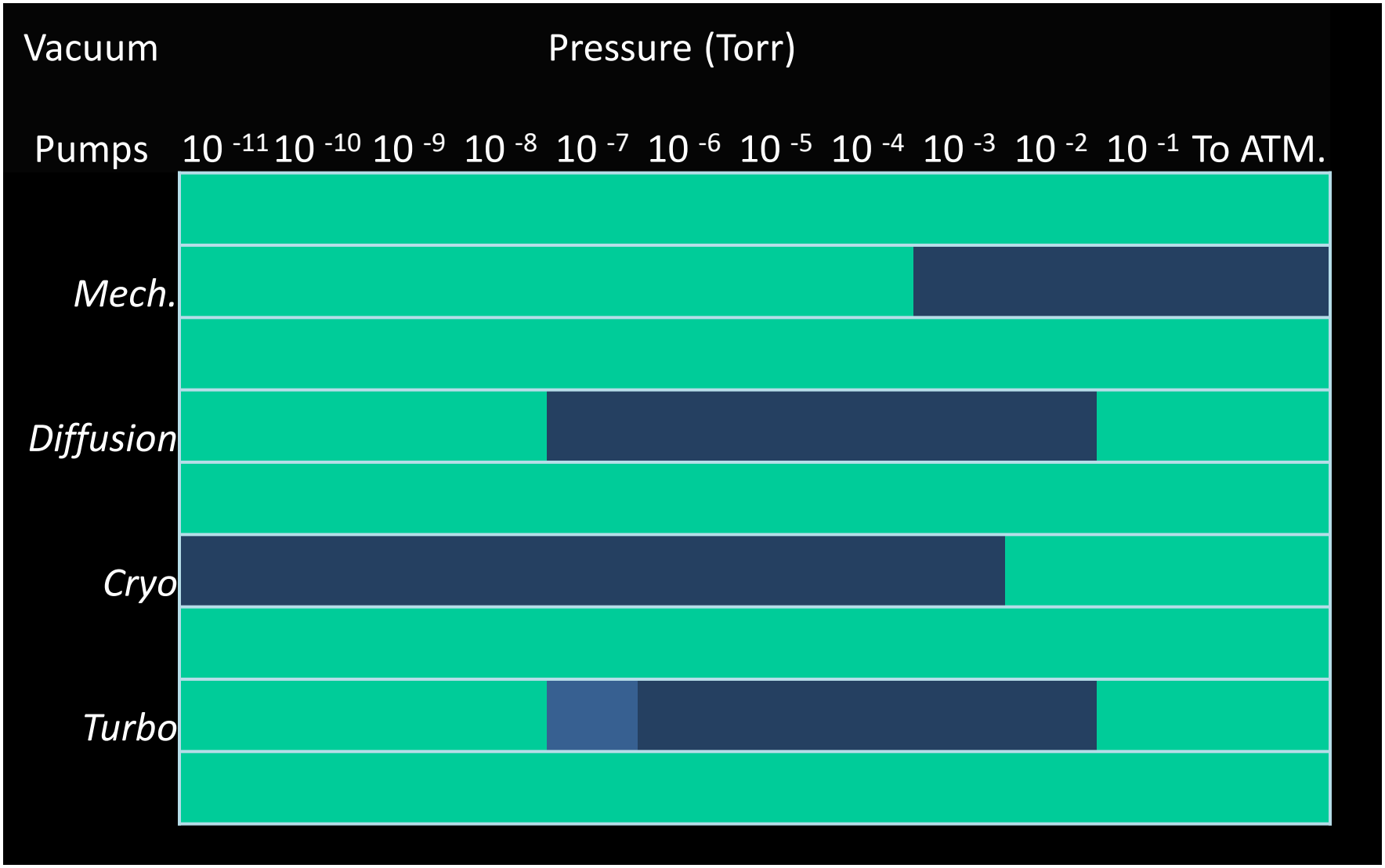
Vacuum Pumps

- Pumps are selected and used based on a number of criteria, including:
  - Vacuum range required
  - Gases to be pumped
  - Pumping speed
  - Overall throughput.
  - Corrosive gas tolerance
  - Cost
  - Maintenance requirements
  - Downtime
- Q. *Do you get all attributes with all pumps?*
- Operational physics dictates the performance.

Typical Ranges for Vacuum pumps



Mechanical Pumps

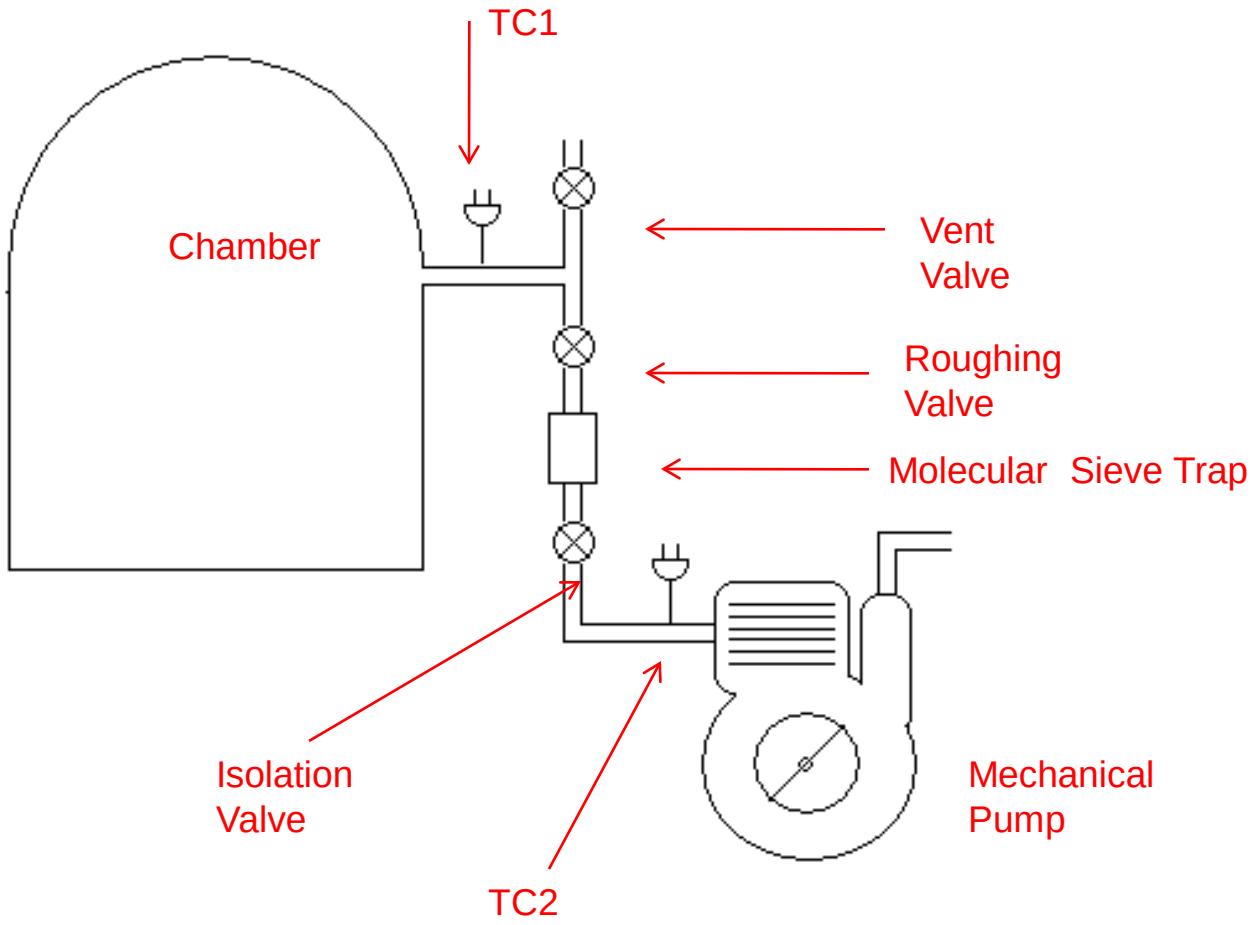
- Capable of reducing pressure to the low vacuum state of approximately 10^{-3} Torr.
- Mechanical pumps are used to initially reduce pressure in a high vacuum system.
- Oil sealed rotary vane mechanical pumps are most common.
- Recall, the amount of water and residual gas at 10^{-3} Torr.

Mechanical Pumps

- Advantages
  - Can pump from 760 Torr
  - Rugged construction
  - Low maintenance
  - Low operating cost
  - Low initial cost
  - Long life
  - Small to very large size

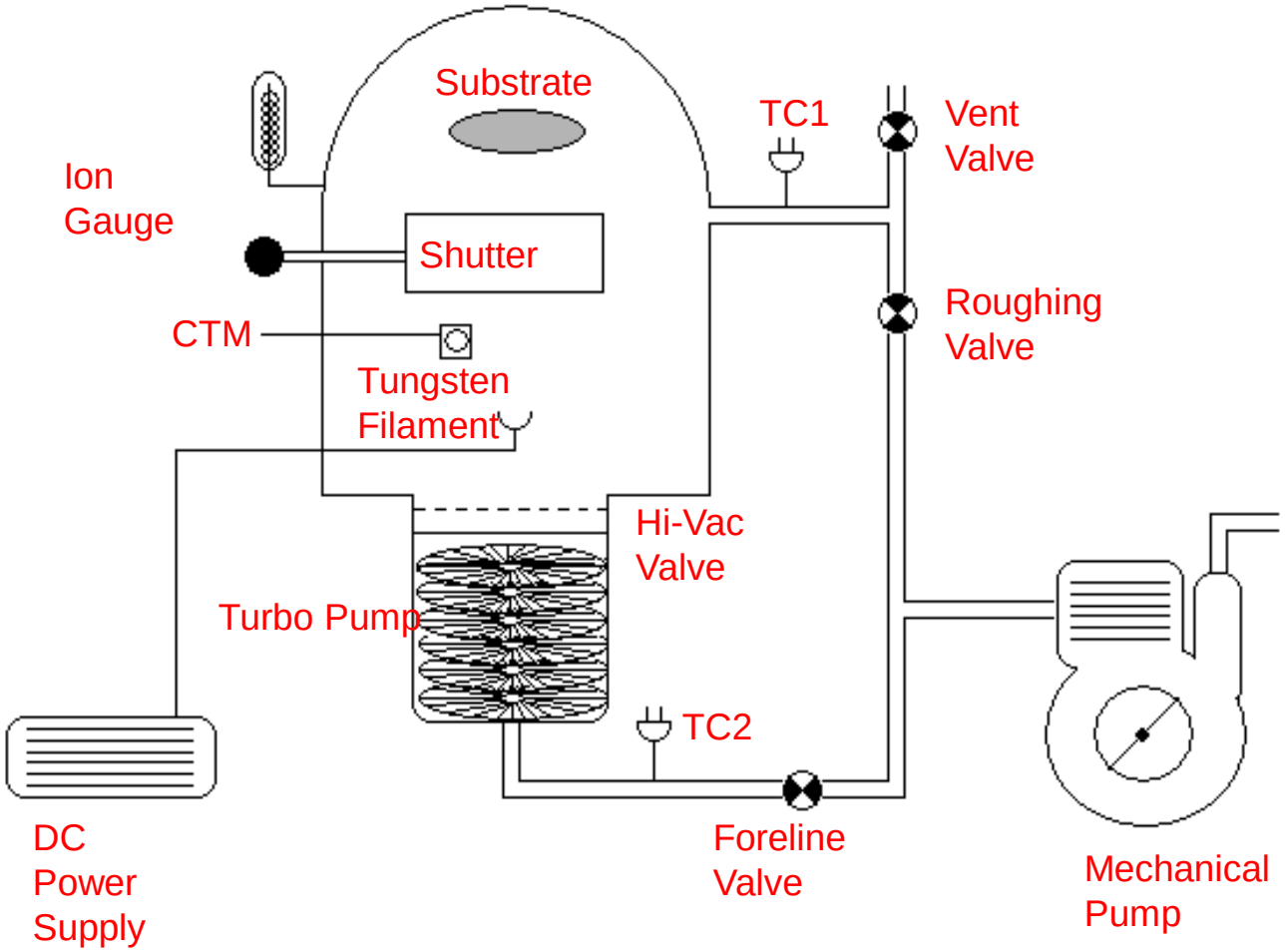
- Disadvantages
  - Backstream oil
  - Noise
  - Speed decreases below 10^{-1} Torr
  - Sensitive to particulates
  - Low frequency vibration

Mechanical Pump System

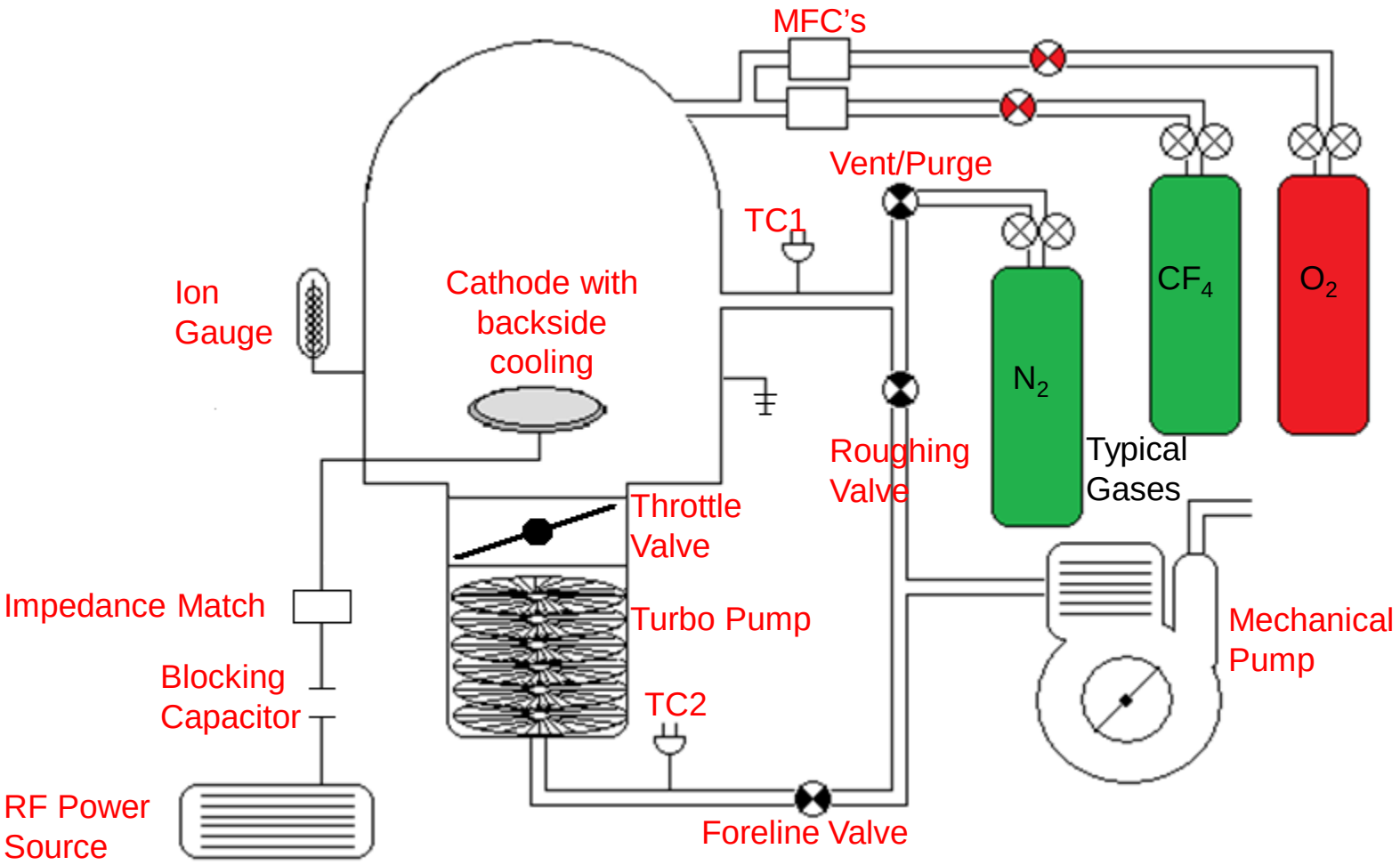


TC = Thermocouple gauge

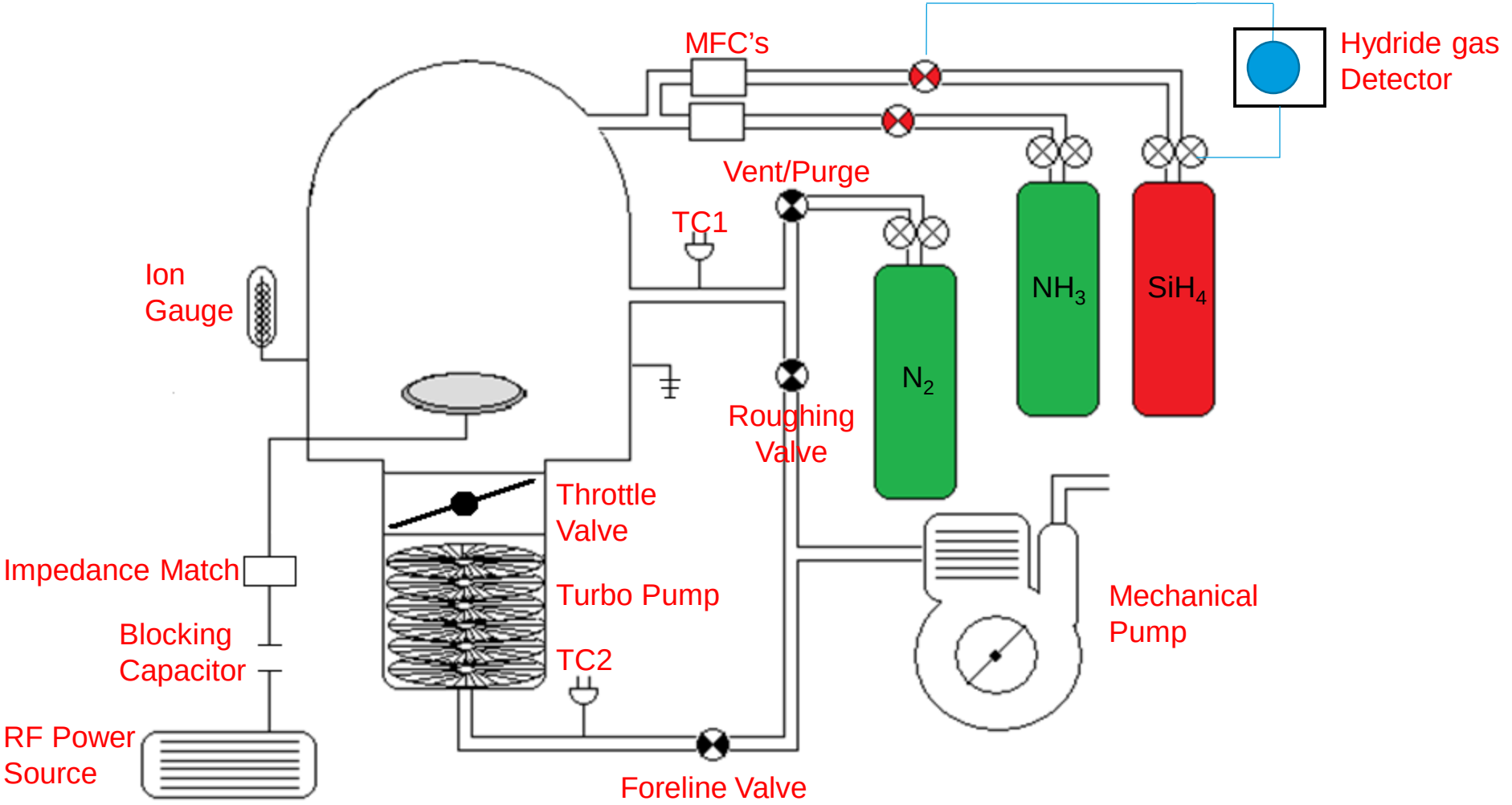
Thermal Evaporator



Reactive Ion Etch



PECVD



Sputtering Tool