Semiconductor Manufacturing Technology

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Chapter 8

Gas Control in Process Chambers

Objectives

After studying the material in this chapter, you will be able to:

1. Explain why process chambers are used in semiconductor manufacturing.
2. Describe the benefits of vacuum, the vacuum ranges and appropriate pumps.
3. Explain the need for gas flow in process chambers and how it is controlled.
4. Explain what is an RGA and why it is beneficial in process chambers.
5. Describe what is a plasma and how it is obtained.
6. Discuss the effects of contamination in chambers and how to minimize it.

The Many Functions of Process Chambers

- Controlling how gas chemicals flow into and react in the chamber in close proximity to the wafer.
- Creating a vacuum environment.
- Removing undesirable moisture, air and reaction by-products.
- Creating an environment for chemical reactions such as plasma to occur.
- Controlling the heating and cooling of the wafer.

Early 1960s Vacuum Bell Jar

- Many fabrication processes involves chemical reactions that take place in process chamber.
- Exposure to moisture, the ambient environment, and contaminants.
- In the beginning, only 2 steps require a vacuum, one is evaporation of Al for contact and Au on back to package.

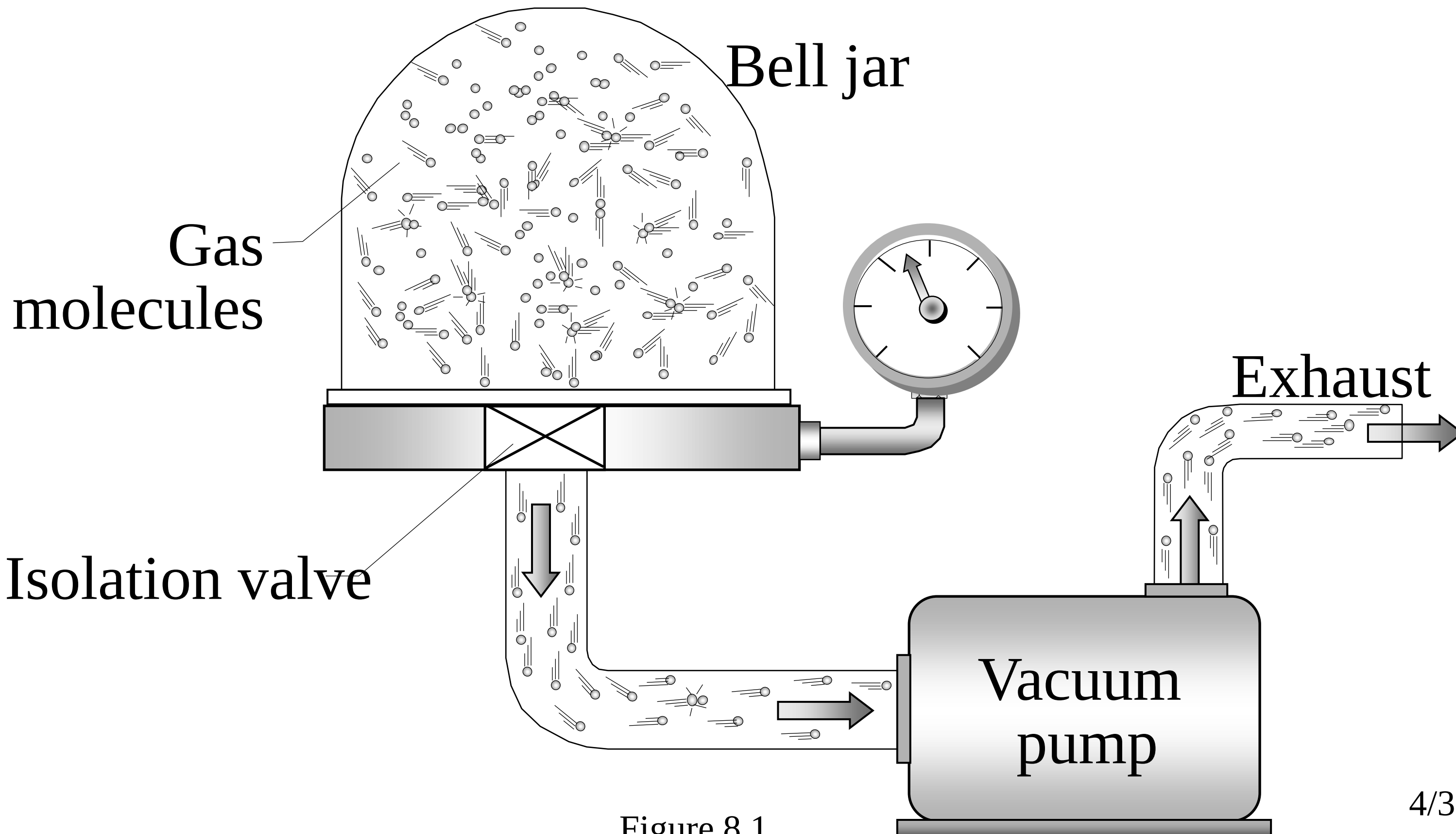
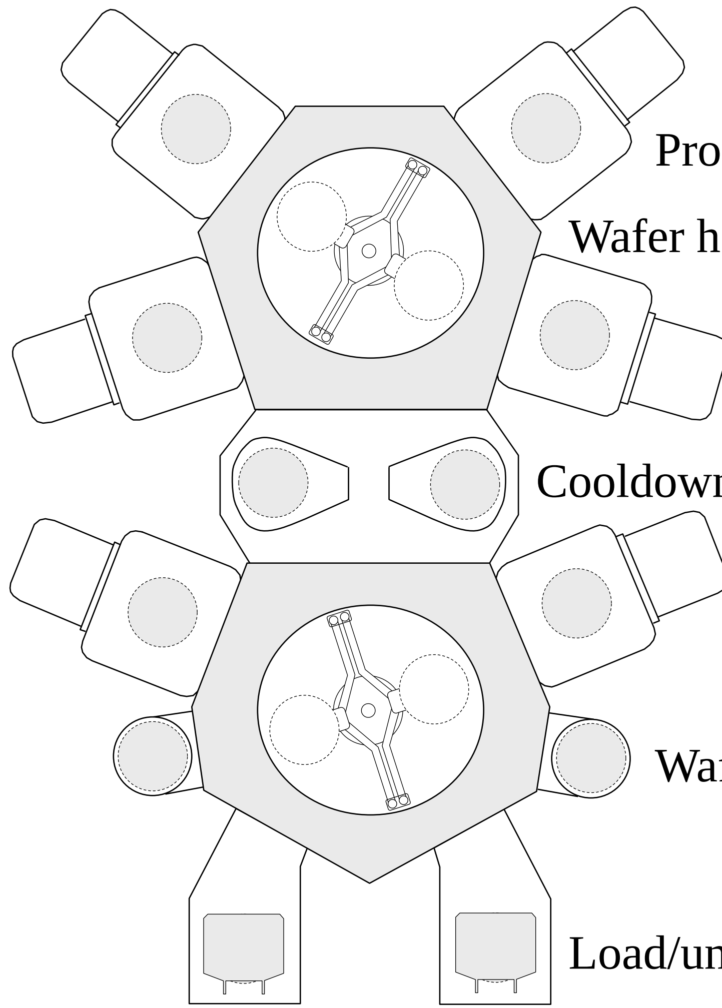


Figure 8.1

Integrated **Cluster** Tool

- The multiple process chambers are clustered around a central transfer chamber with a robot arm.
- Wafers are transported from process chamber to process chamber under vacuum, eliminating native oxide, reducing contamination.
- Increasing throughput.



Used with permission from Applied Materials, Inc., Endura PECVD system

Figure 8.2

Vacuum

- A vacuum exists when there is less pressure in an enclosed volume than in the surrounding atmospheric pressure.

- Benefits of Vacuum
- Vacuum Ranges
- Mean Free Path

Benefits of Vacuum in Semiconductor Manufacturing

Vacuum Condition	Benefit
1. Create clean environment	Particles, unwanted gases, moisture and contaminants are removed by a vacuum pump.
2. Low molecular density	Reduce the number of molecules in the system to reduce contamination and to move a gas out of the way (lower molecular interference).
3. Extend distance between collisions of molecules (Mean Free Path)	Necessary condition for creating the plasma needed in semiconductor processes such as sputtering and etch.
4. Accelerate reactions	Vacuum helps accelerate processes by lowering the vapor pressure of materials, so they can react faster with other chemicals.
5. Create a force	Vacuum creates a force, such as a vacuum pick-up on a robot arm.

Table 8.1

Vacuum Ranges

- The vacuum of deep space is about 10^{-16} torr.

	Vacuum Ranges in Torr				
Wafer Fab Processes	Rough $759 - 10^{0}$	Medium $10^{0} - 10^{-3}$	High $10^{-3} - 10^{-6}$	Ultra High $10^{-6} - 10^{-9}$	Chapter in book
Oxidation					10
Photo					13 - 15
Polish					18
Etch					16
Deposition					11
Metallization					12
Ion Implant					17
Metrology					7

Table 8.2

Mean Free Path and Molecular Density Versus Pressure

MFP: the **average** distance a gas molecule moves before it **strikes** another molecule

	760 Torr (atmosphere)	**1×10^{-3} Torr**	**1×10^{-9} Torr**
# of molecules/cm^3	3×10^{19} (30 million trillion)	4×10^{13} (40 trillion)	4×10^{7} (40 million)

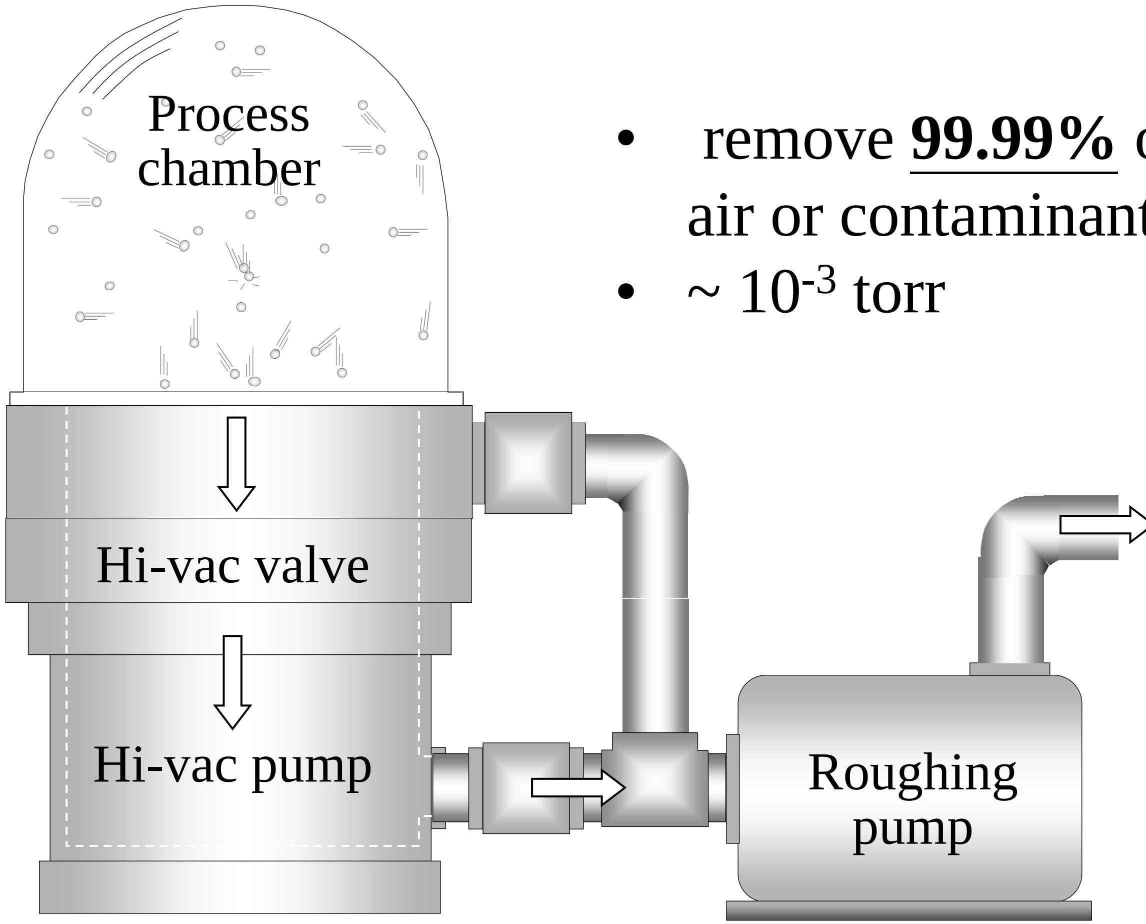
	760 Torr (atmosphere)	**1×10^{-3} Torr**	**1×10^{-9} Torr**
Mean free path	2×10^{-6} in	2-in	30 miles

Table 8.3

Vacuum Pumps

- Roughing Pump
  - Dry Mechanical Pump
  - Blower/Booster Pump
- High Vacuum Pump
  - Turbomolecular Pump
  - Cryopump
- Vacuum in Integrated Tools

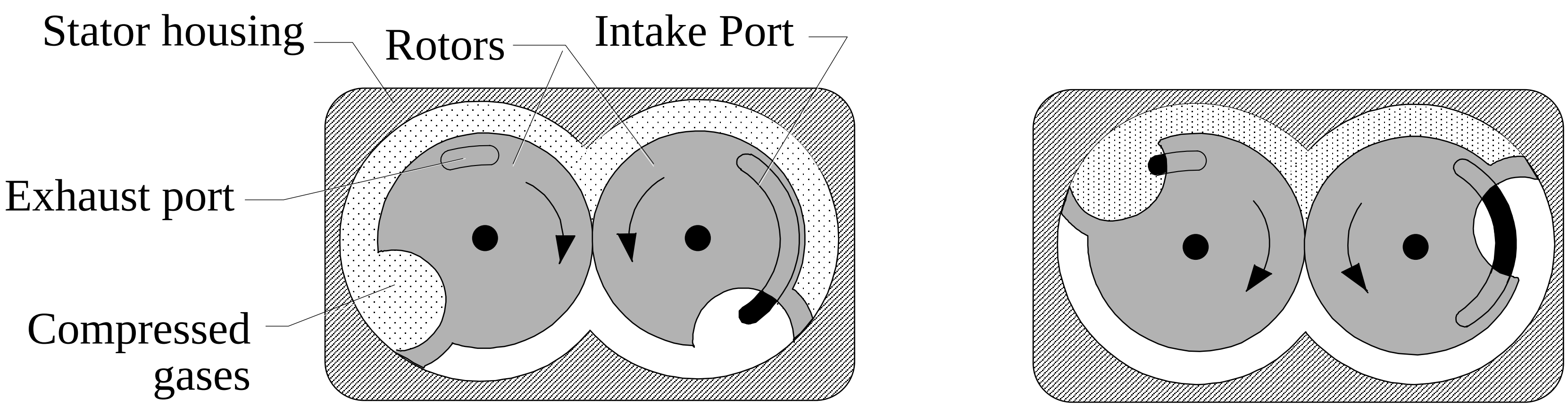
Roughing Pump Exhausting a High Vacuum Pump



- remove **99.99%** of the initial air or contaminants
- ~ 10^{-3} torr

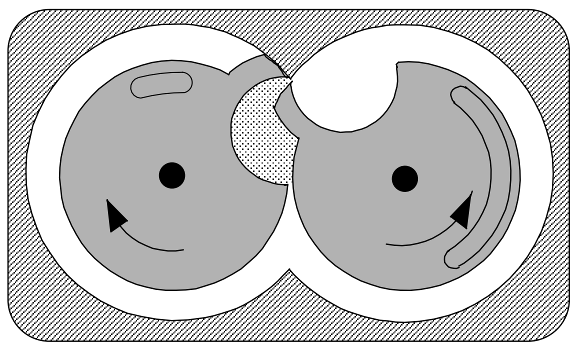
Figure 8.3

Rotary Claw Dry Mechanical Pump



(a) (b)

- 10^{-3}~10^{-9} torr
- Use **<u>nonmetal</u>** materials on the moving surface to avoid the use of **<u>oil</u>** sealing or **<u>lubricants</u>**



(c)

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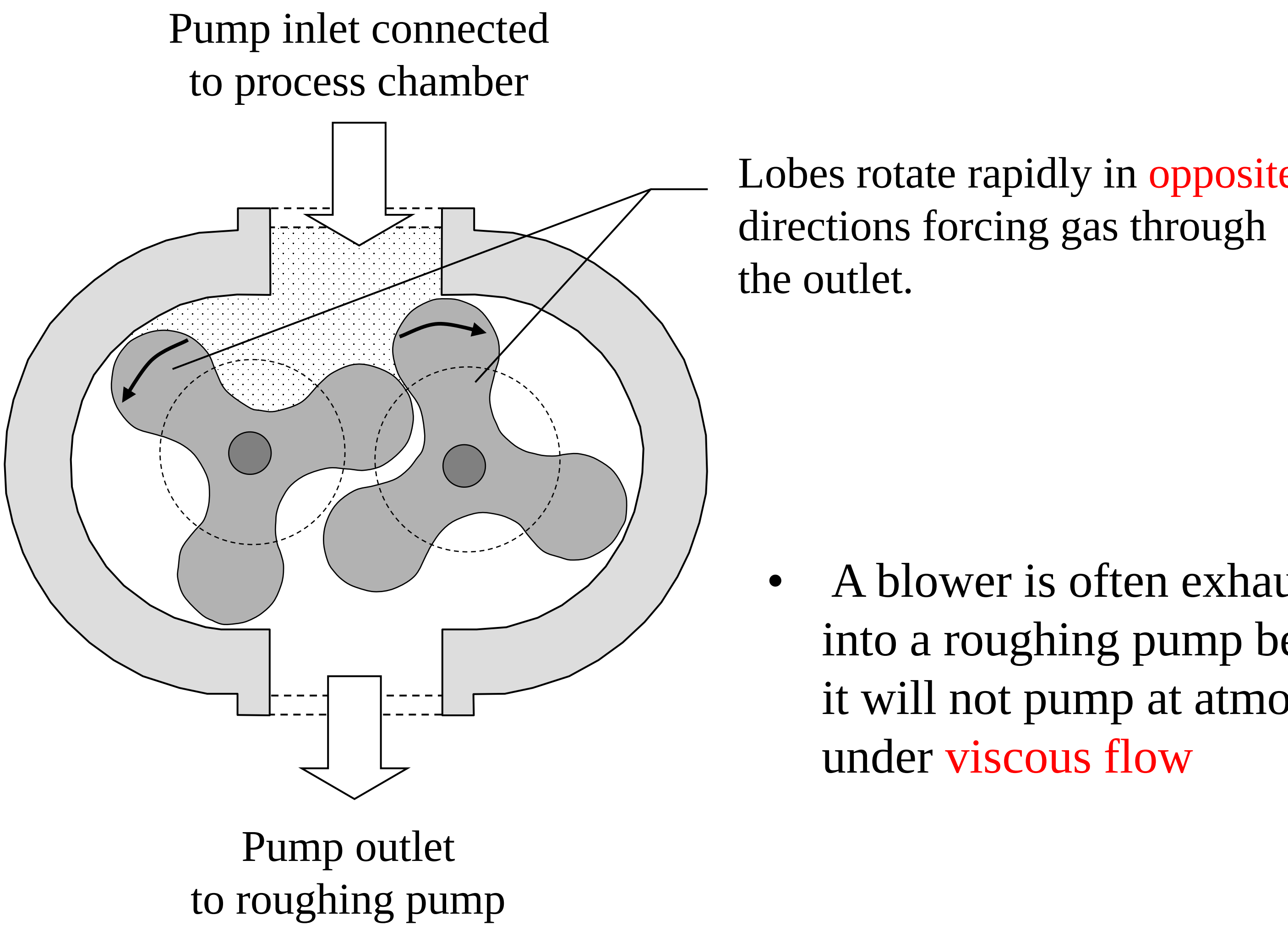
Figure 8.4

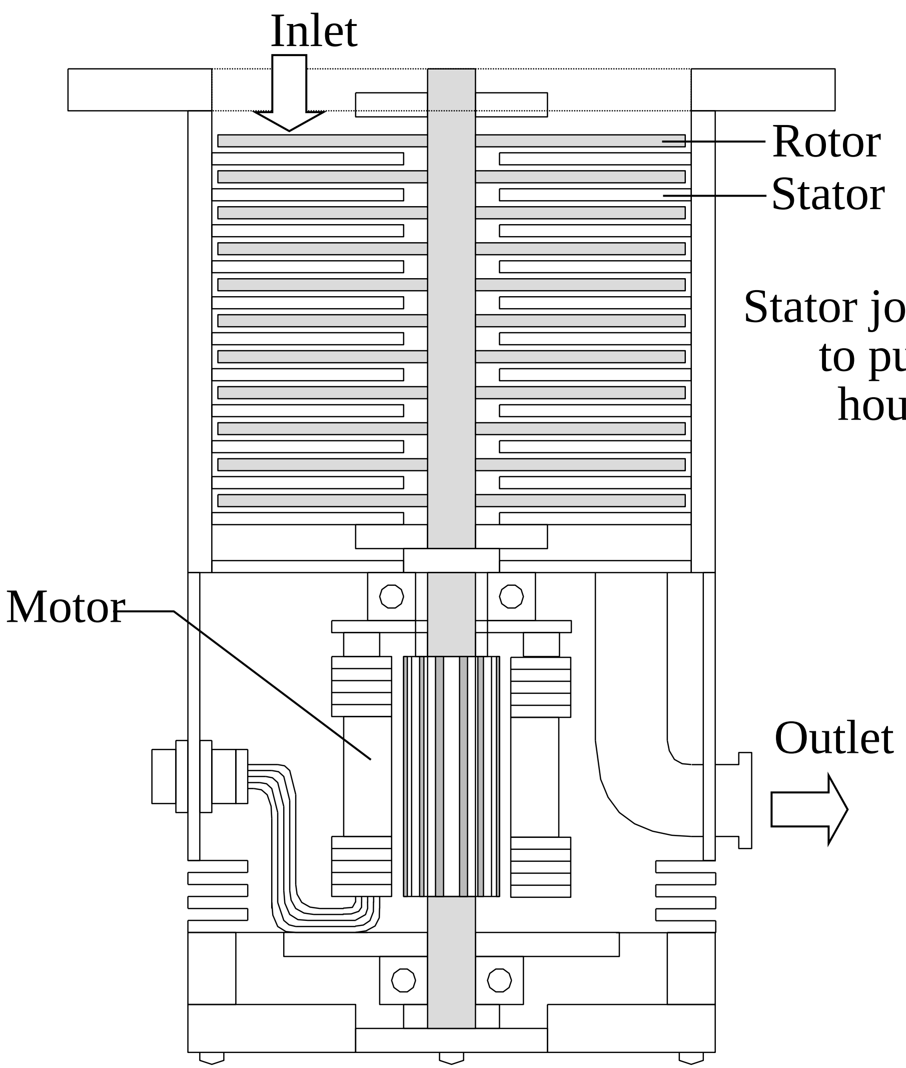
Roots Blower Pump

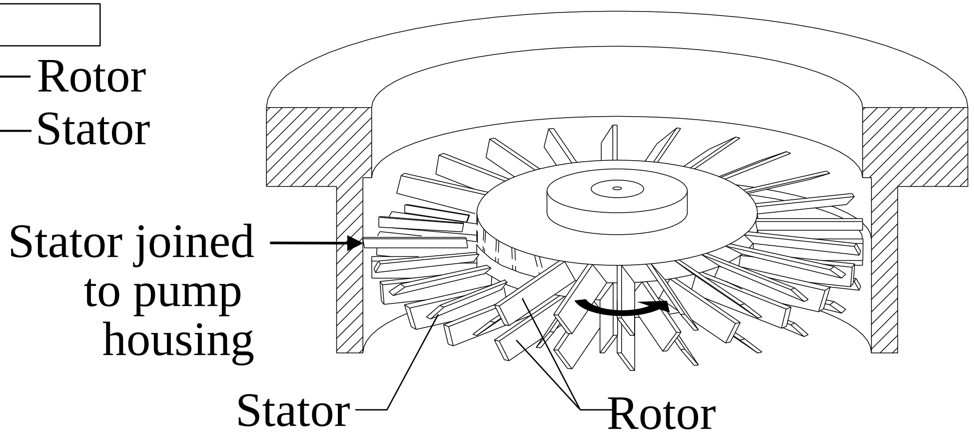


- A blower is often exhausted into a roughing pump because it will not pump at atmosphere under viscous flow

Figure 8.5

Turbo Pump Blades

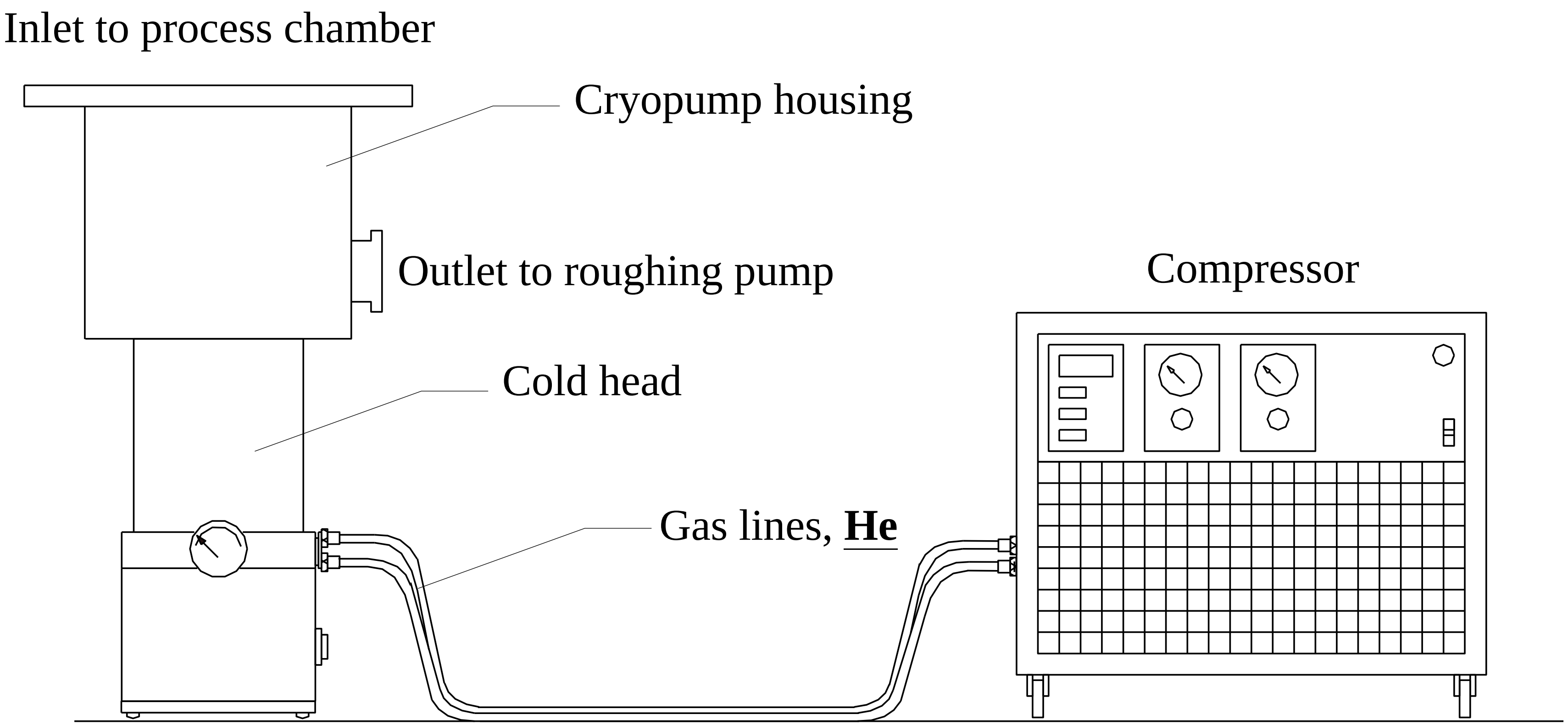




- ~ 10^{-10} torr
- Like jet engine
- This pump gives a fast start-up to full pumping action once turn on
- Principle: **mechanical** compress
- **90,000 RPM**, to a roughing pump
- Same as roots, it cannot pump with viscous flow at atmosphere pressure
- High gas throughput
- 10-40 stator/rotor

Cryopump Compressor and Pump Module

- Making gas **cold** that they are **frozen** and **captured** in the chamber
- With no oils or moving parts, common used



Used with permission from Varian Vacuum Systems

Figure 8.7

Cryoarray Surfaces in Pump Module

- Cyropumps require a roughing pump and to remove the air from the pump and vacuum system
- These captured gases are removed periodically called **regeneration**, where pump is **warmed** and gases are **vent**

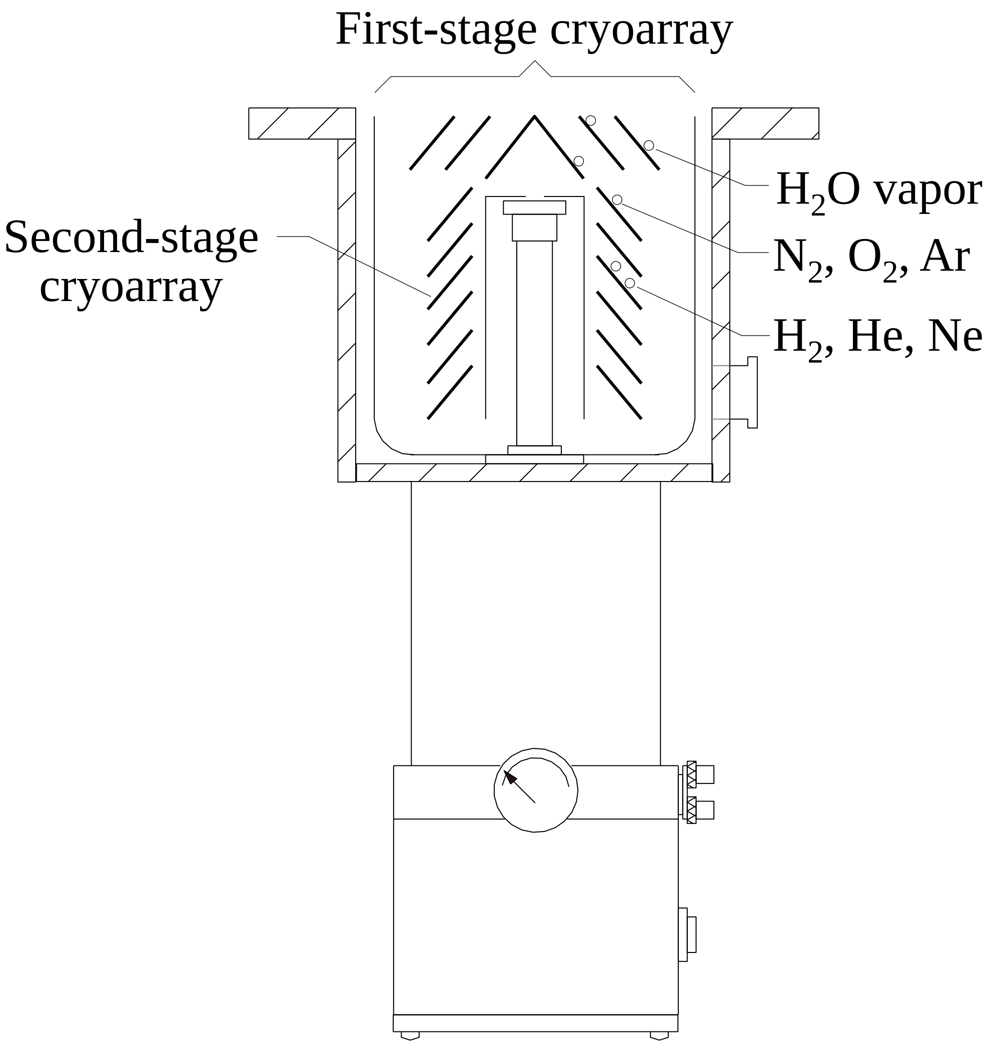


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Figure 8.8

Cluster Tool Layout with Vacuum Environment

- **Loadlock is where wafers enter the cluster tool, isolating the inner regions of the tool from the workplace environment**
- **Provide a well controlled, and low contamination environment**

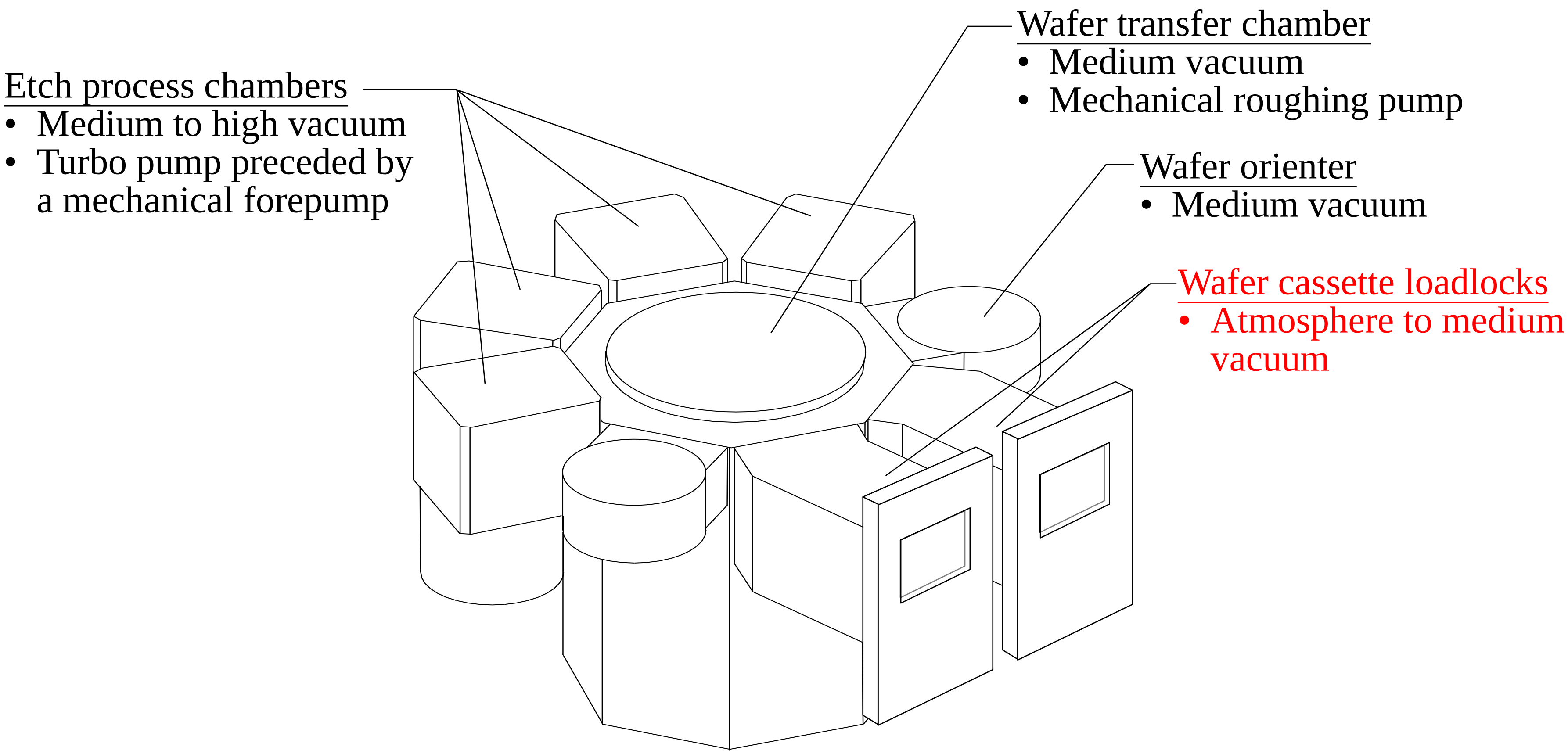


Figure 8.9

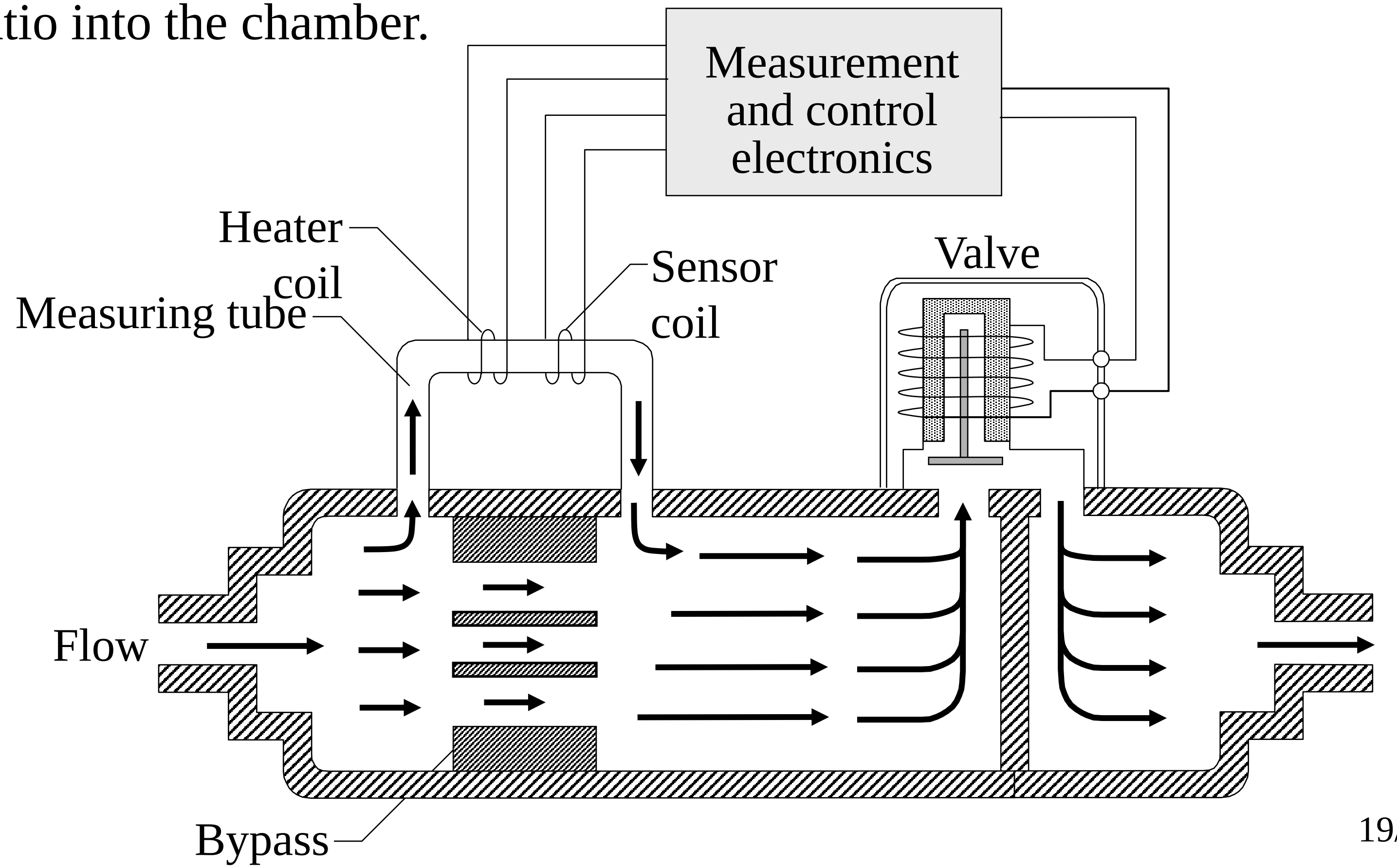
Process Chamber Gas Flow

The basic process chamber requirements for gas flow are:*

- Ability to handle a wide variety of bulk and specialty gases, many of which are **corrosive** and **toxic**.
- The control of gas flow into the process chamber is accurate and repeatable.
- The gas mix proportions are able to be controlled during the process run.
- Materials used in the chamber are not affected by the process gases and do not introduce contaminants into the gas stream.
- Common unit: standard cubic centimeters per minute (sccm) or standard liters per minute (slm)

Thermal Mass Flow Controller [MFC]

- Idea gas law: the number of gas molecules in a given volume changes in proportion to the absolute pressure and temperature
- Thus, controlling gas only by volume will not always yield the same number of gas molecules, which is undesirable for controlling chemical reactions
- MFC employs a heat-transfer property of the gas to directly measure the mass flow ratio into the chamber.



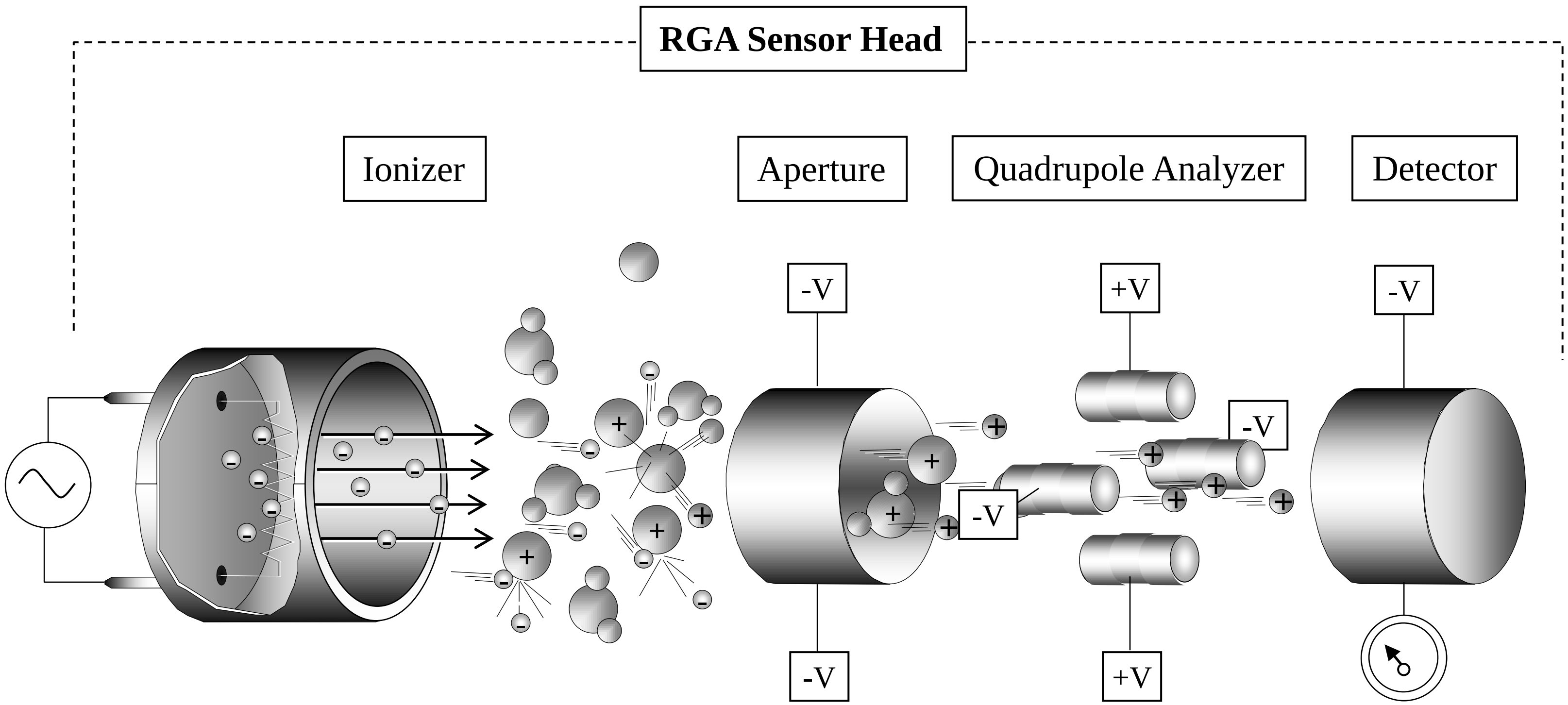
Mass Flow Controller

(Photo courtesy of MKS Instruments, Inc.)

Photo 8.1

Basic Parts of Residual Gas Analyzer (RGA)

- Used for leak detection, analysis of contamination, and as a troubleshooting tool



Hot filament generates high-energy electrons.

Electrons collide with atoms from inside the process chamber to create +ions.

High negative voltage accelerates +ion movement.

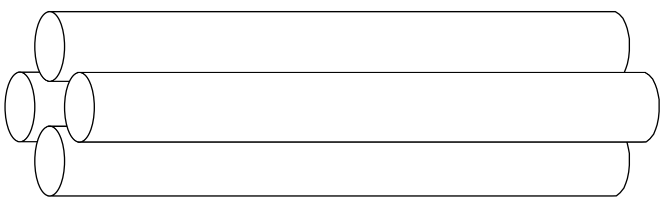
DC and RF voltages on four rods selectively filter +ions by their respective mass-to- charge value.

The detector recombines electrons with +ions and measures the intensity of specific ion current.

Figure 8.11

Quadrupole Mass Filter

- It consists of four cylindrical rods that have both a constant DC potential and a high-frequency RF component
- For a given voltage level applied to the cylinders, only ions of a given atomic mass-to-charge pass through the filter



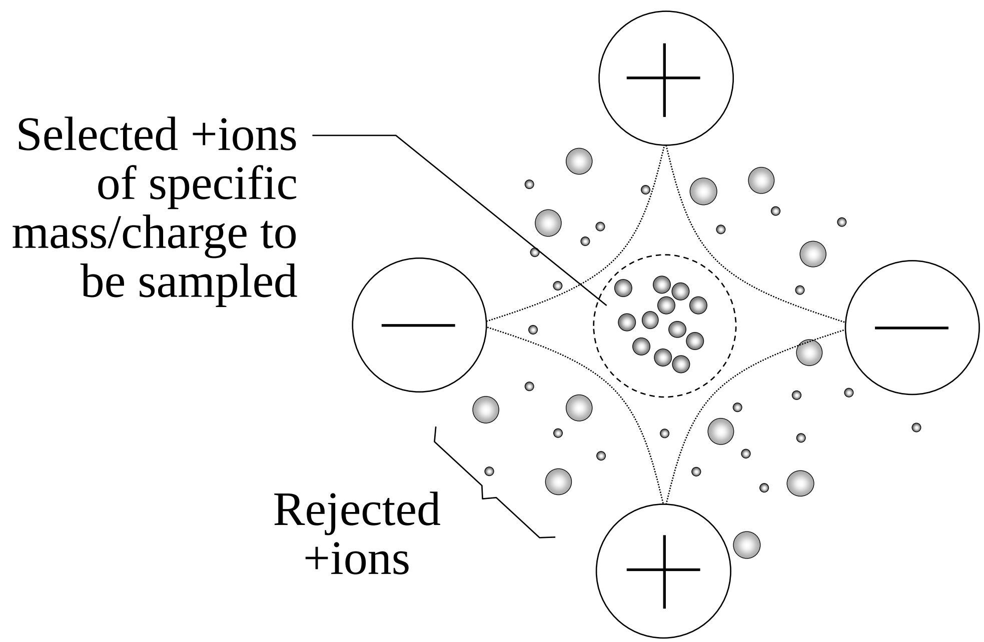


Figure 8.12

RGA Measurement of a Process Chamber

- Real time information about cleanliness and stability of the process chamber during pump down.
- Diagnosis of process problems

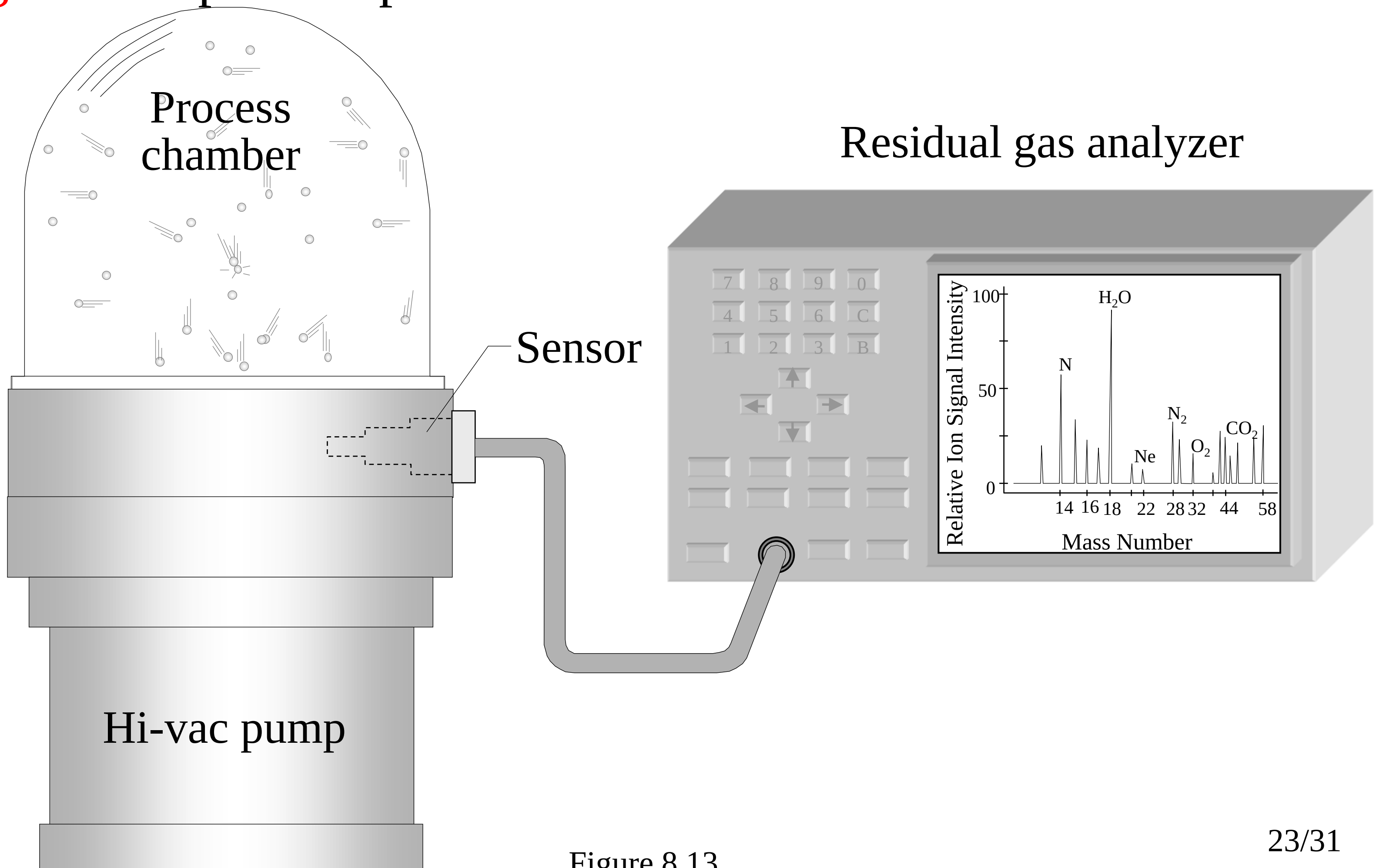


Figure 8.13

Plasma

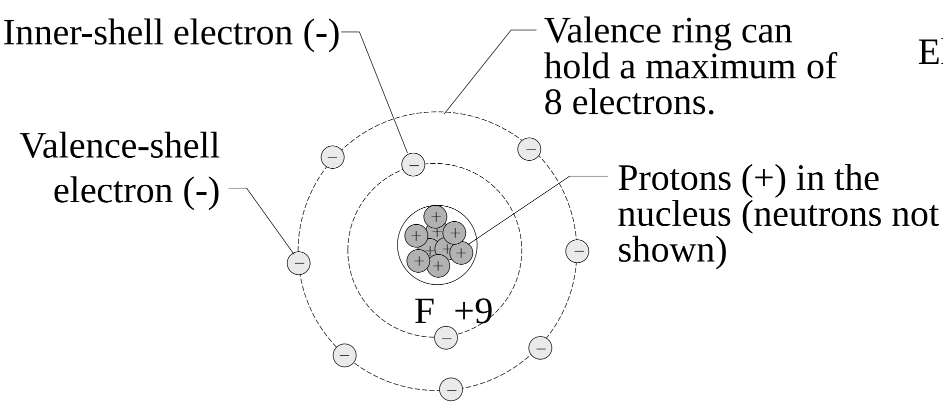
- Plasma is a neutral, highly energized, ionized gas consisting of neutral atoms or molecules, positive ions, and free electrons
- Ionization of gas atoms in a confined process chamber can occur by strong DC or AC electromagnetic fields or by bombarding the gas atoms with sort of electron source.

- Creation of an Ion (Ionization)
- Glow Discharge (Excitation and Relaxation)
- Radicals (Dissociation)
- RF Energy

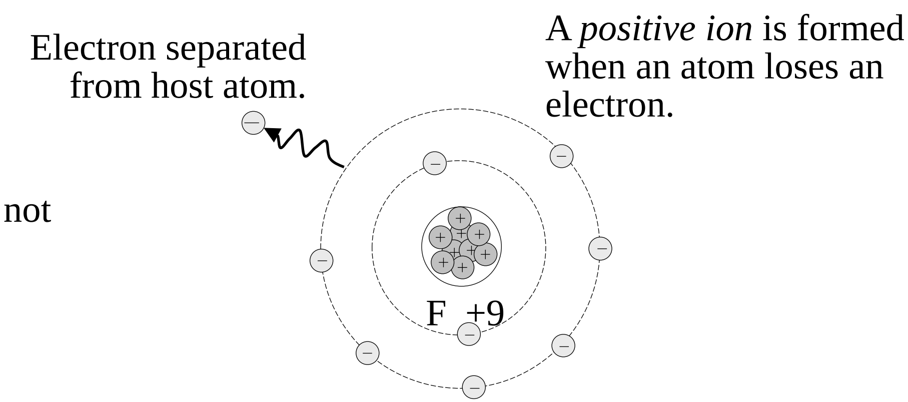
Creation of an Ion

A neutral particle is an atom with an equal number of protons (+9) and electrons (-9).

An ion is an atom with an unequal number of protons (+) and electrons (-).



Fluorine atom has a total of 7 valence electrons.



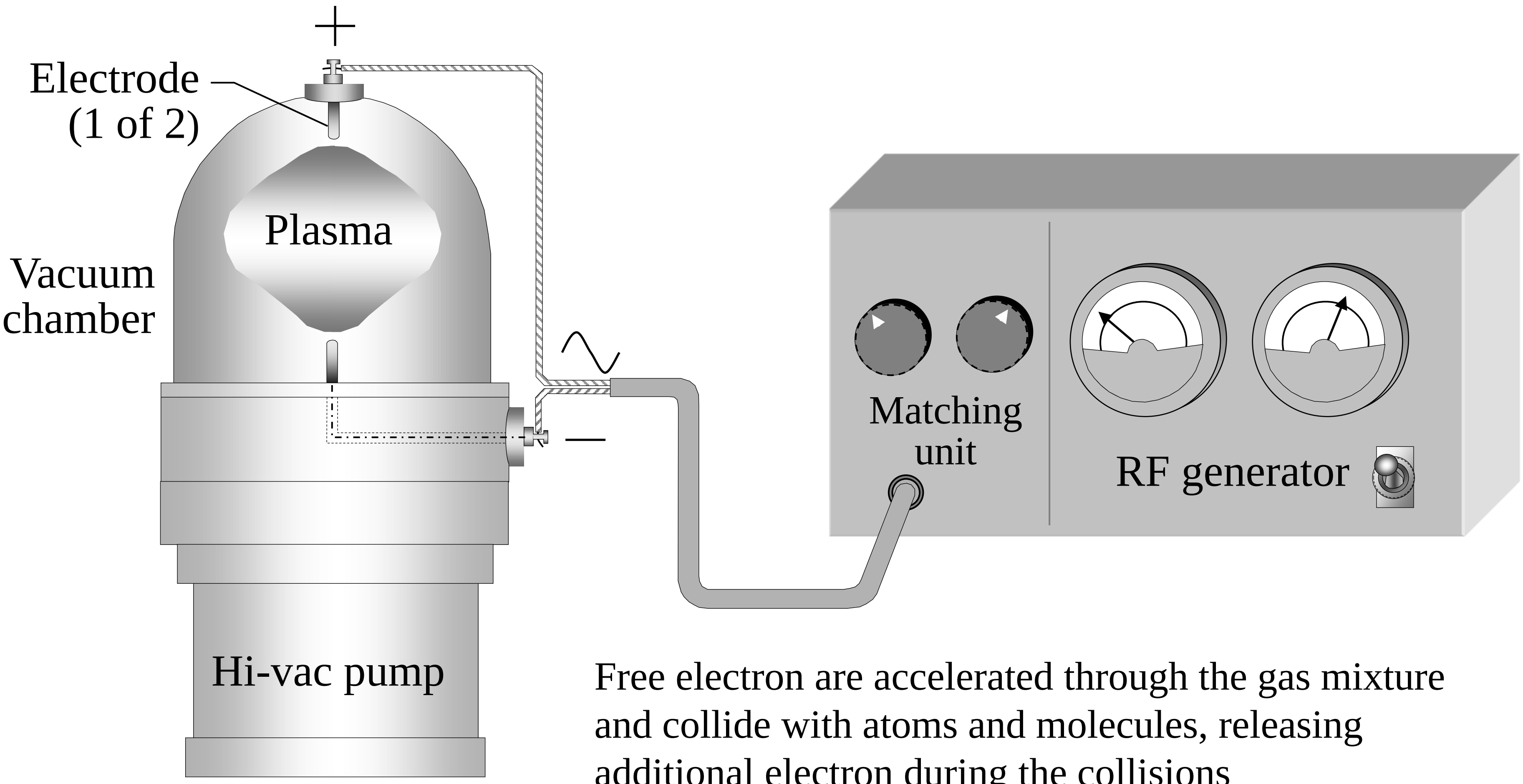
Fluorine atom with one less electron.

e.g., $F \rightarrow F^{+} + e^{-}$

Figure 8.14

Plasma Glow Discharge

- The most common indication that a plasma exists in a process chamber is the characteristic observable light referred to as a glow discharge



Free electron are accelerated through the gas mixture and collide with atoms and molecules, releasing additional electron during the collisions

Figure 8.15

Electrically Exciting and Relaxing an Atom

- Life time of excited electron ~ 10^{-9} sec
- Typical parameters sustaining a glow discharge include the RF power and frequency, pressure, gas mixture and flow rate, vacuum pumping speed and surface temperature

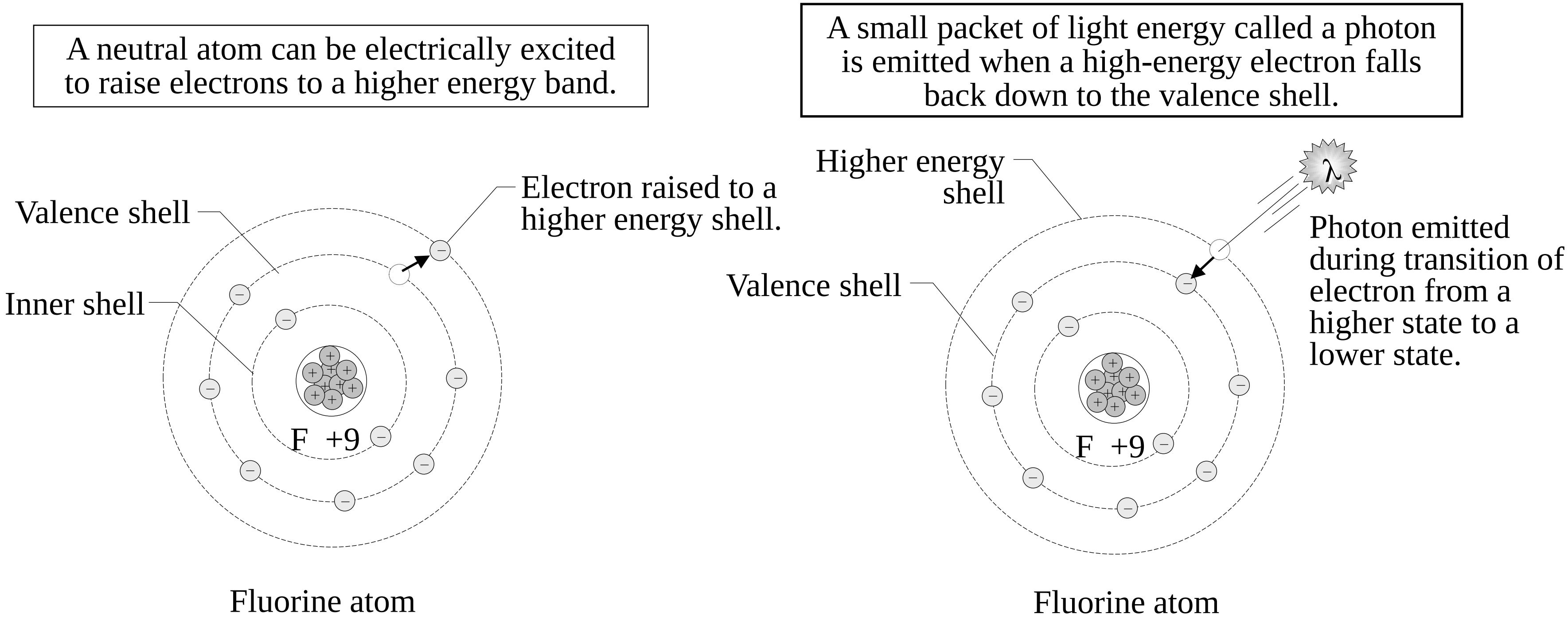


Figure 8.16

Dissociation of a Molecule

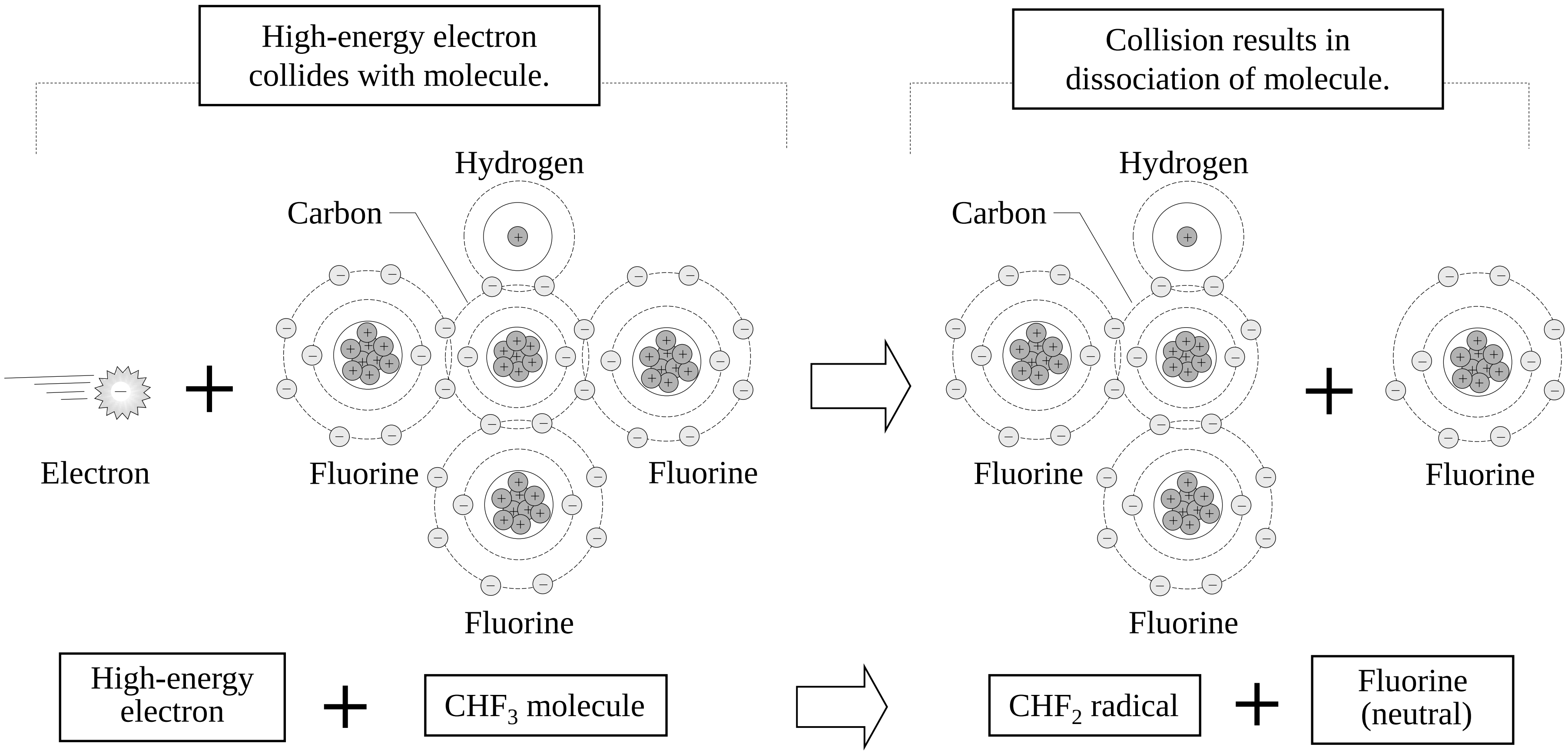


Figure 8.17

Typical Plasma Electrode Configuration

- Electrons in the glow discharge can move **faster** toward the positive electrode when compared to slow moving massive positive ions
- **Dark space**: lack of electron
- **Positive** ion accelerates toward electrode→ second e → maintain the glow discharge

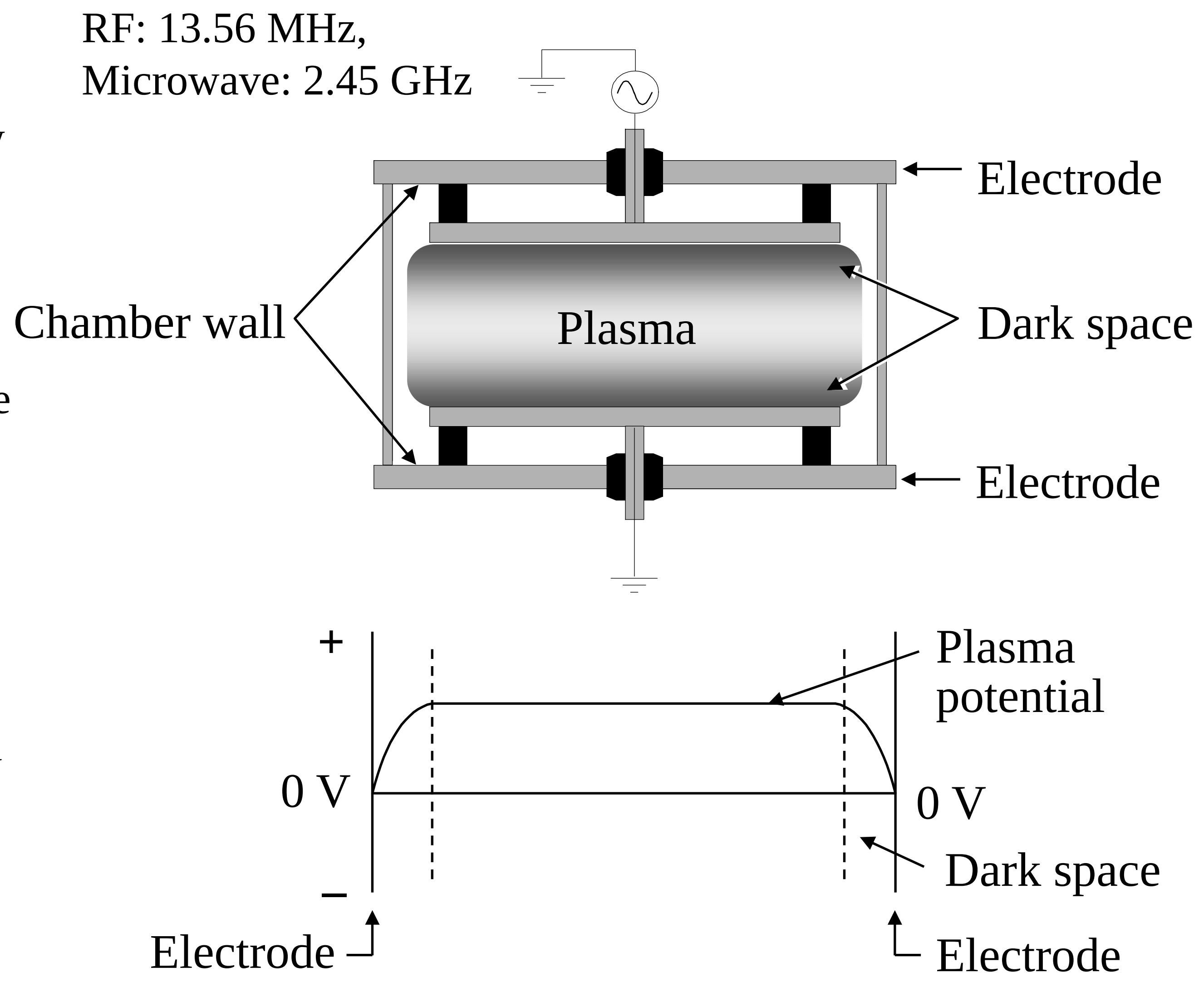


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Figure 8.18

Process Chamber Contamination

Recommendations to Minimize Contamination during Equipment Servicing
1. Maintain good temperature and humidity control in the cleanroom environment where the equipment is located.
2. Control the equipment's pump and vent cycles to minimize turbulence and prevent particle generation when processing wafers.
3. Avoid abrasive cleaning materials.
4. Use exact replacement parts and materials to avoid subtle sources of equipment contamination.
5. Use low particle-generating gas-handling components, such as regulators and automatic valves that have a tendency to generate particles.

Table 8.4