Basic Nanotechnology Processes

E SC 212

Unit 7
Advanced Etch Systems

Lecture 1
The Tools for Plasma Removal Processes

Outline

- Introduction
- Etch Systems
- Cluster Tools

Types of Etch Systems

- Plasma etch reactors can be grouped into three broad groups:

1. Sputter etch – physical process, etches by ion bombardment only, uses a non-reacting gas, it is anisotropic and non-selective
2. Chemical etch – chemical process, specially selected gases to react with materials, ion bombardment is negligible, it is isotropic and selective
3. Combined etch – ion bombardment complements chemical etch, varies from isotropic to anisotropic with fair selectivity

Plasma Etch Systems

- The term plasma etch systems can refer to any system that uses plasma generation in order to etch a sample
- A sample can be biased to improve bombardment’s effect on the etching. This is call Reactive Ion Etching (RIE)
- A sample can be left unbiased which takes way much of the effects of bombardment, leaving chemistry as the dominant etching force. This is known as Plasma Etch (PE)

Etch Systems

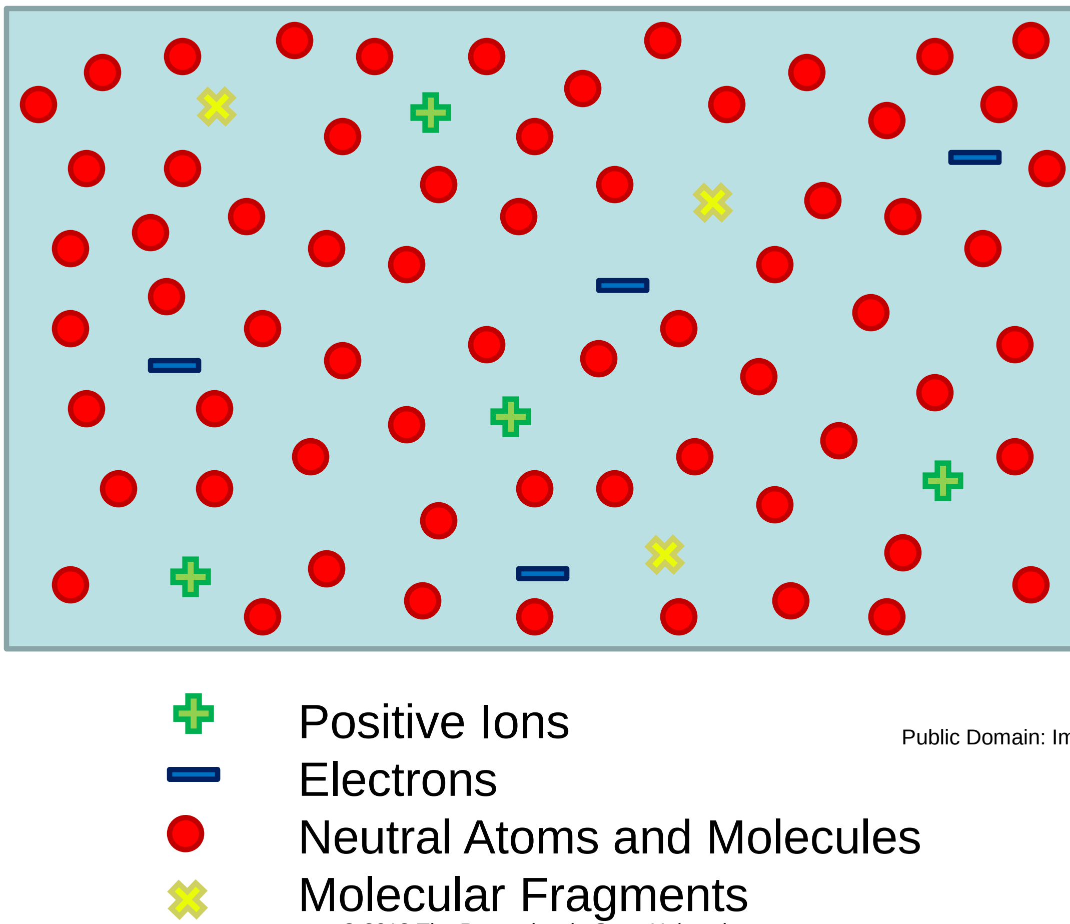
- Horizontal Plate RIE
- Parallel Plate Etch
- Microwave Etch
- Electron Cyclotron Resonance (ECR) Etch
- Hexode RIE
- MERIE
- Inductively Coupled Plasma (ICP) Etch
- Ion Beam Etch
- Advanced Strip and Passivation (ASP)

Horizontal Plate RIE

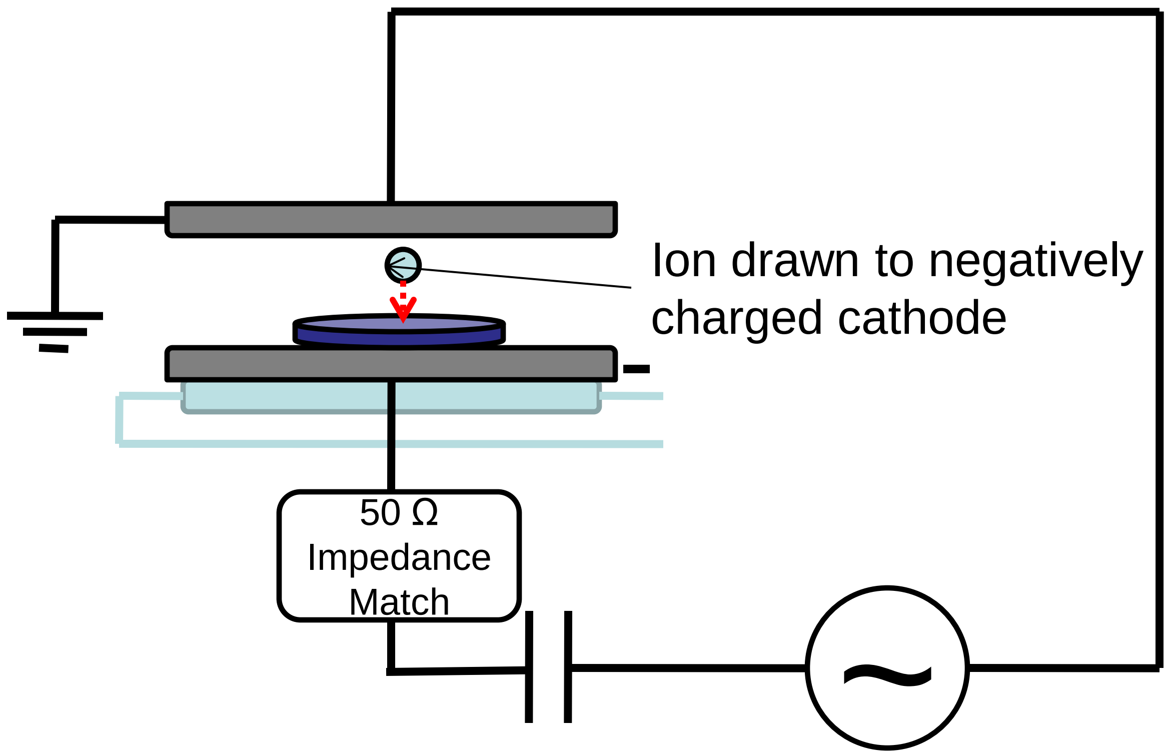
- This is the system that we have studied, and drew a detailed block diagram of an in-depth understanding of the system in E SC 212.
- The substrate is placed on a powered cathode
- The cathode is generally water-cooled to remove the heat generated by ion bombardment.
- Chamber walls usually function as the anode, and may also be temperature controlled.

Generic Parallel Plate Plasma Model

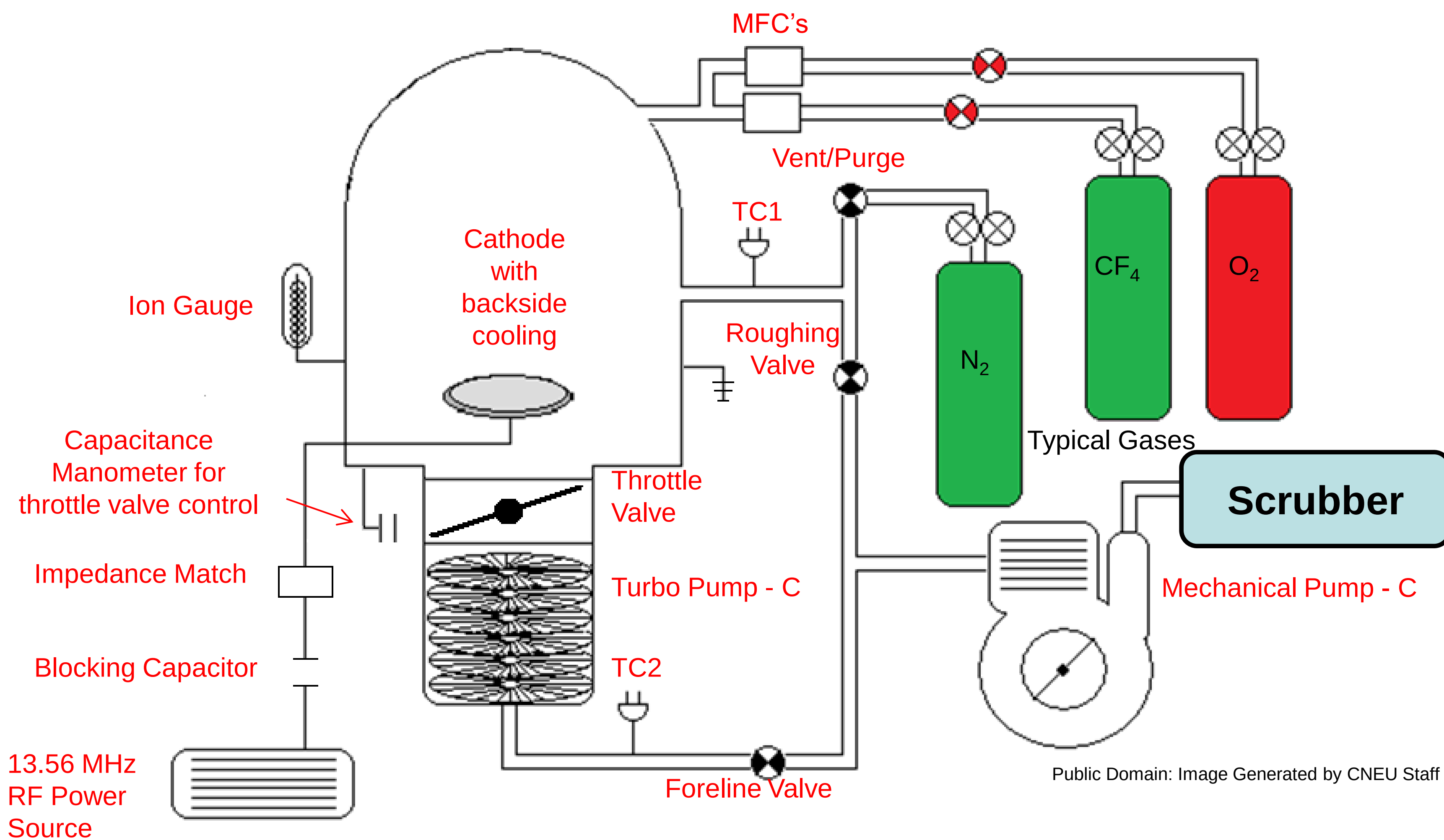
The majority of the plasma body consists of etch gas molecules, etch by-product molecules and radicals. A typically low density plasma consists of less than 1% charged species.



Simple Diagram of a Horizontal Plate RIE



Typical Horizontal Plate Reactive Ion Etch System



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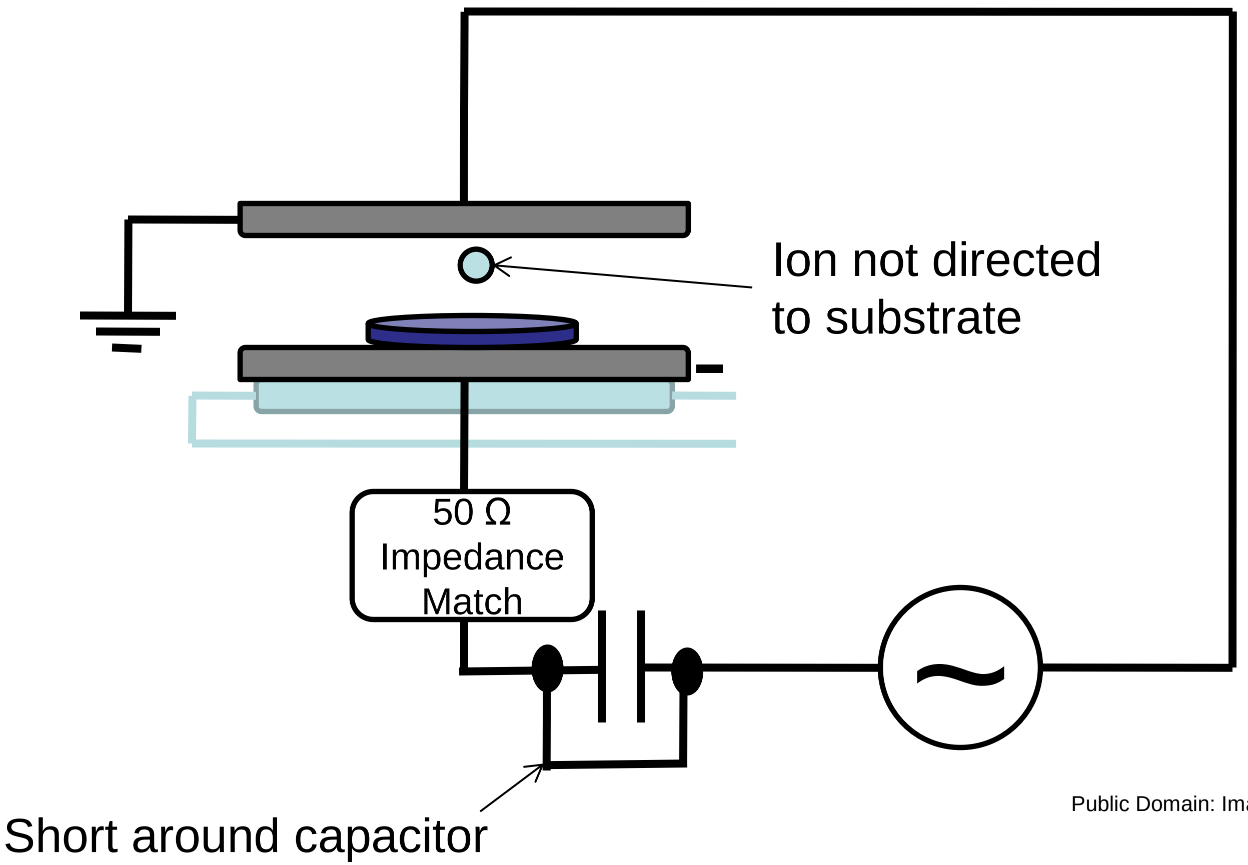
Simple Diagram of a Parallel Plate (Planar)



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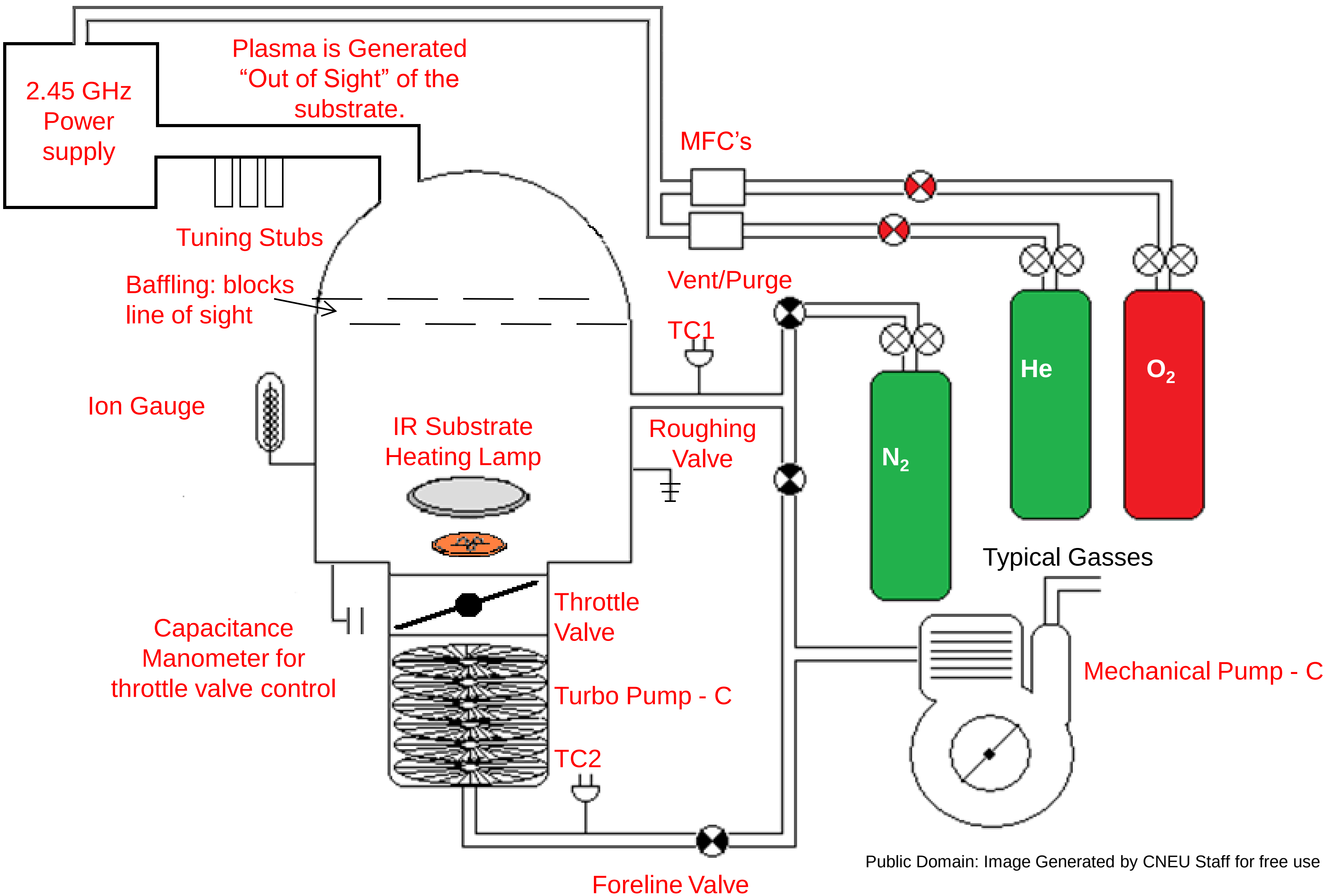
Microwave Etch

- Plasma is formed in a tuned microwave cavity remotely located from the etch chamber
- A UV light source may be used to ignite the plasma
- Active gas species flow through a showerhead into the etch chamber
- Heaters are generally used to increase the rate for photoresist ashing
- This system is often called a down stream asher

Microwave Etch



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Electron Cyclotron Resonance Etch (ECR)

- ECR uses lower pressures than a conventional parallel plate RIE to be able to achieve cyclotron resonance. Lower pressures offer these advantages:
  - Reduced particles
  - Reduced residues and contamination
  - More inherent anisotropy
- The disadvantages are:
  - More damage due to increased MFP
  - Less chemistry
  - Difficult to achieve a uniform plasma greater than 6 inch diameter

Electron Cyclotron Resonance Etch (ECR)

- The design provides a high ion density at low pressure to more effectively transfer energy to the free electrons and at the same time keep them in the plasma region longer.

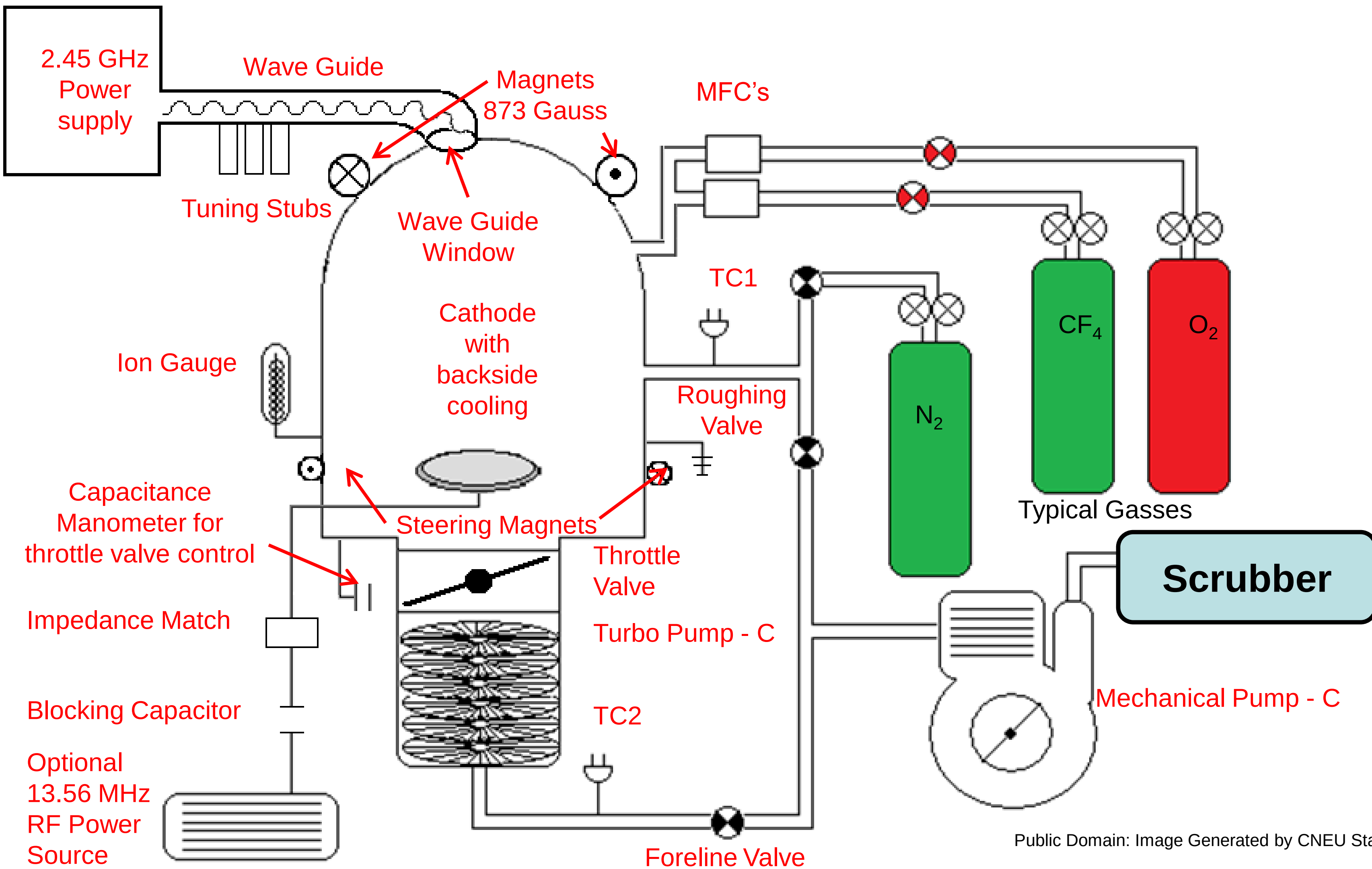
Electron Cyclotron Resonance Etch (ECR)

- A magnetic field parallel to the direction of the flow causes the free electrons to travel in a spiral path.
- The frequency an electron travels around the spiral is determined by the magnetic flux density.
- Maximum energy can be transferred when the frequency of electrons spiraling around magnetic flux line (electron cyclotron frequency) is equal to the frequency of applied electric field.

Electron Cyclotron Resonance Etch (ECR)

- Additional magnets may surround the substrate area to aid in plasma uniformity
- Relatively high bombardment damage and inability to etch substrates larger than 150mm generally make this technically obsolete.

Typical ECR Etch System



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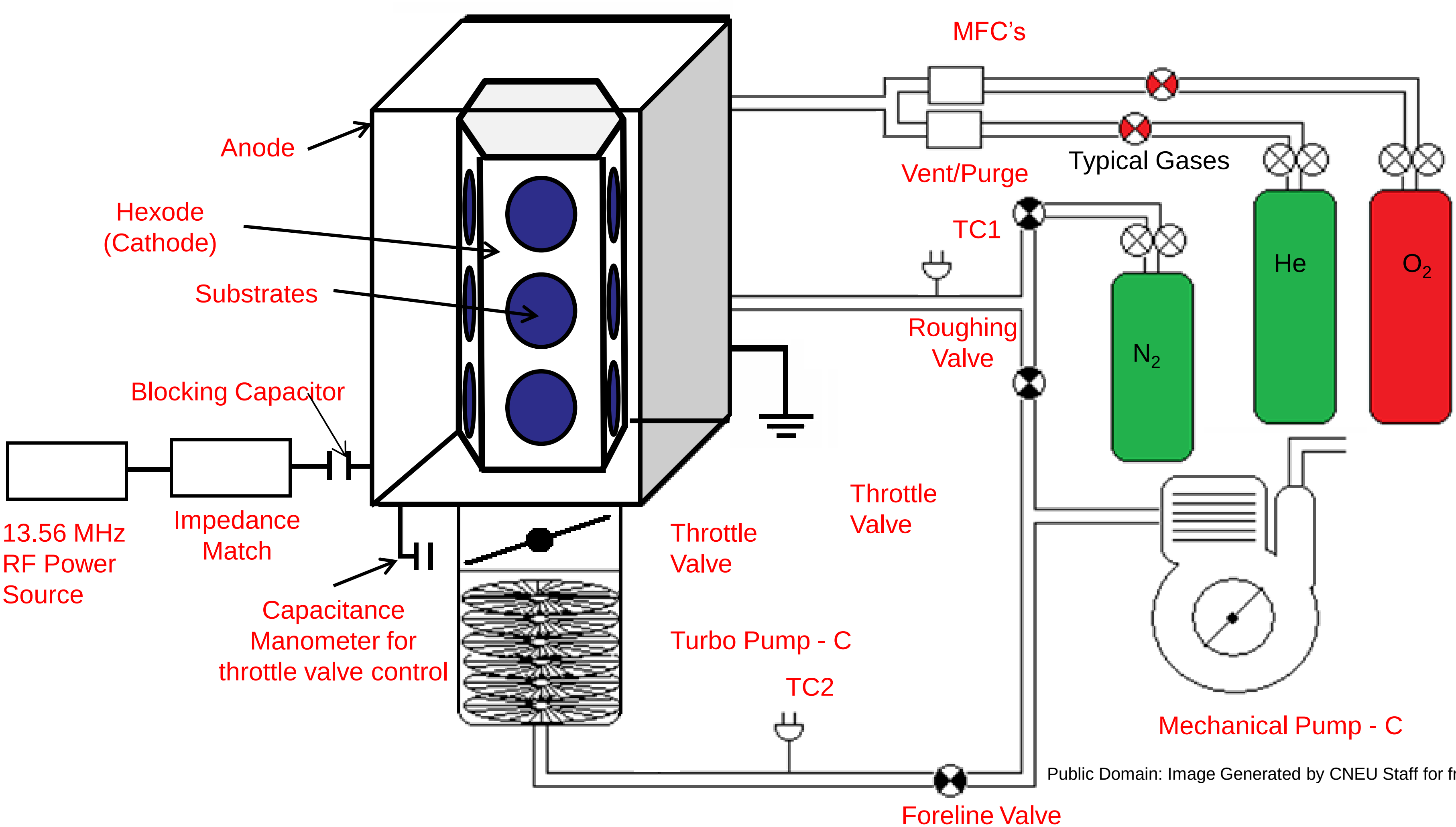
Hexode RIE

- This is a batch type RIE.
- This system holds substrates vertically on the six-sided cathode.
- The chamber walls are grounded to act as the anode.
- Let’s discuss the design, and how this would impact the recipe, and material processing…..

Hexode RIE



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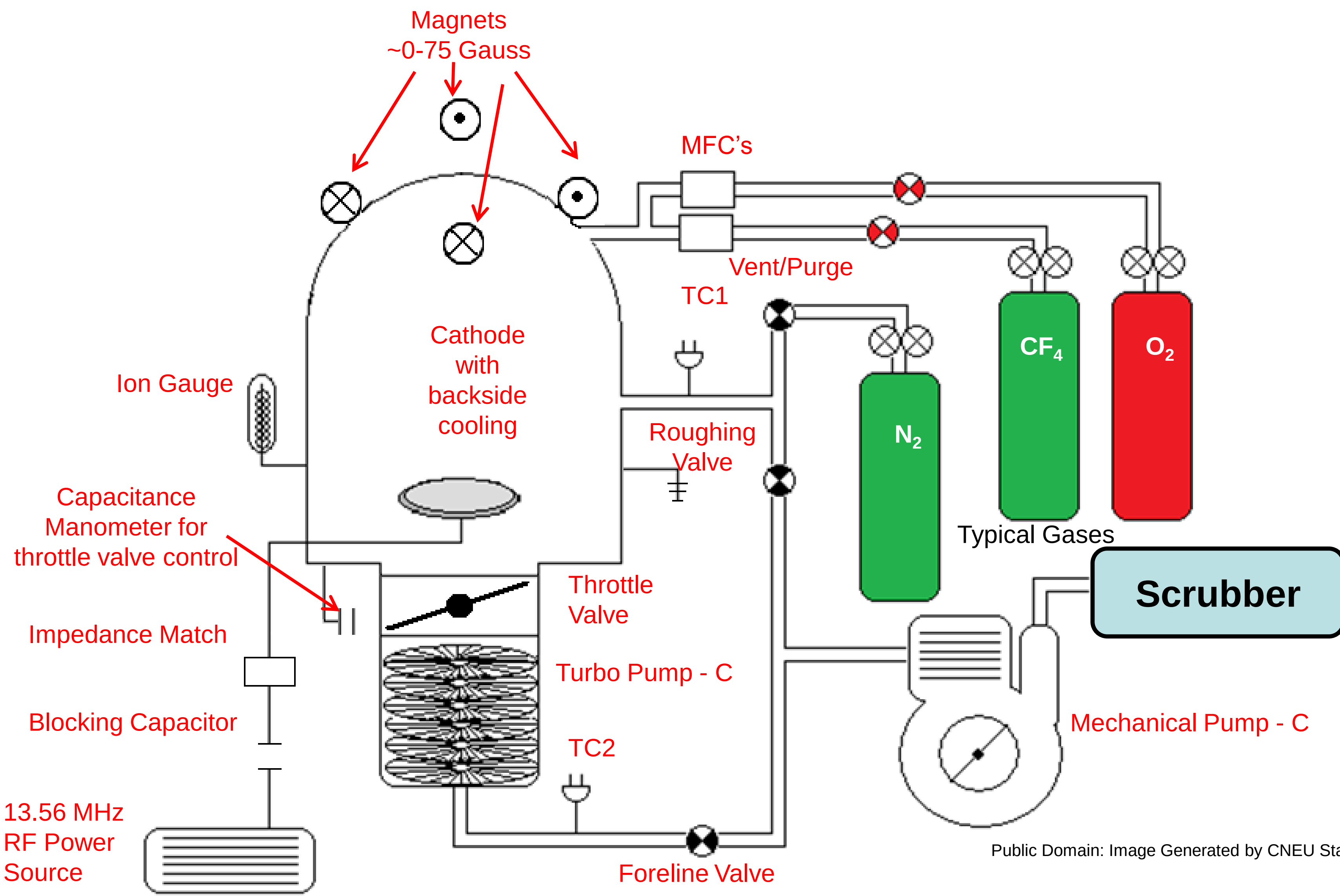
Hexode RIE

- The hexode system is often used for isotropic processes.
- Pressure is relatively high, in the 100’s mT range to provide high concentration of chemical reactants
- DC bias is minimal due to the high pressure and large cathode

Magnetically Enhanced RIE (MERIE)

- Similar to a Horizontal Plate RIE with the addition of a magnetic field in the plasma chamber to confine the plasma away from the grounded chamber walls
- Magnetic field also increases the electron and ion concentration
- The magnetic field is produced by electromagnets surrounding the outside of the chamber. Nominal value of the magnet energy is 60 Gauss.
- Three phase AC current powers the magnets and creates a rotating magnetic field. This field creates uniformity in the etch.

Typical MERIE System



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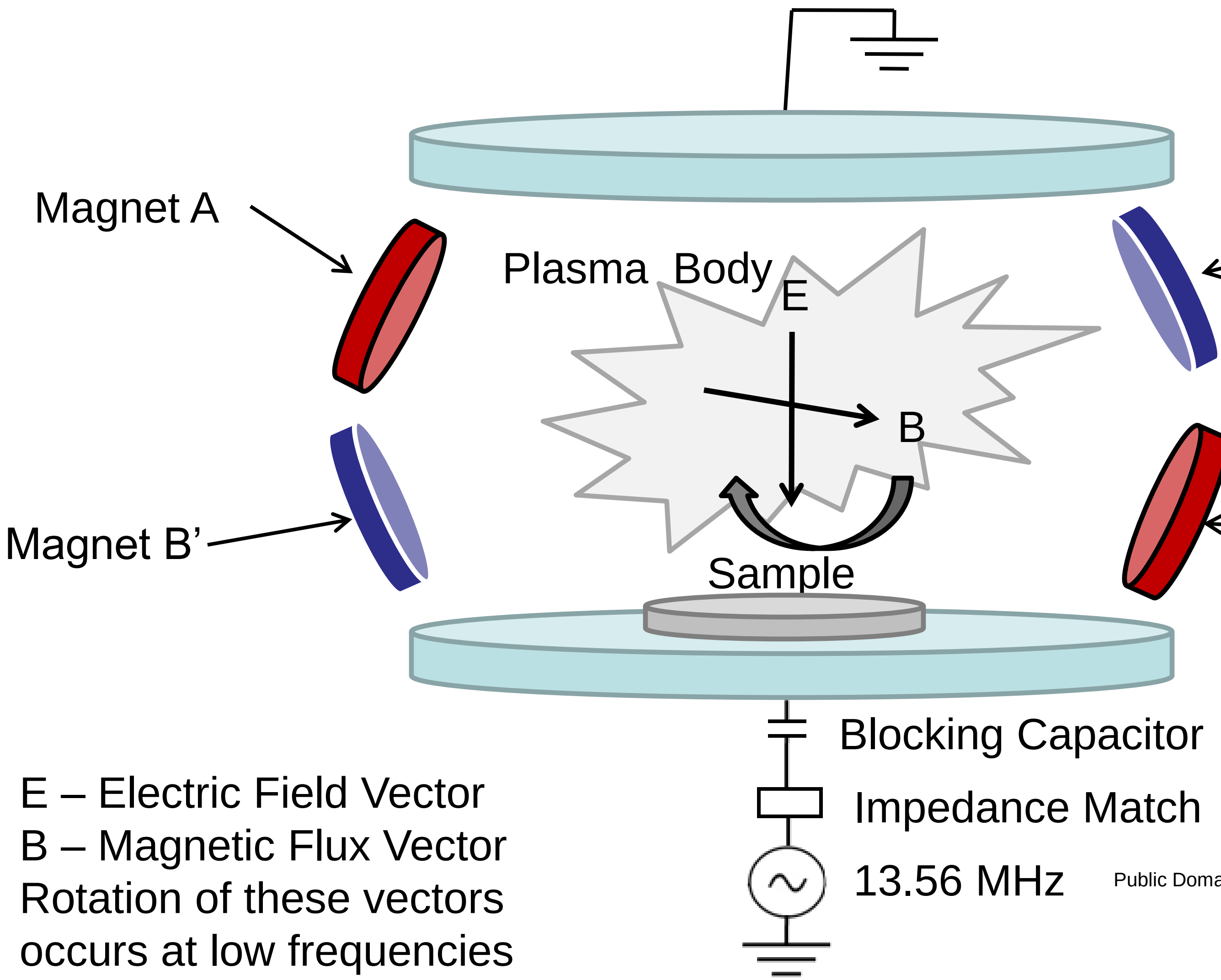
Magnetically Enhanced RIE (MERIE)

- As in the ECR, the plasma is confined with a magnetic field and the electron and ion densities are increased
- The magnetic field is about 1/10th of the power of the ECR (nominally 60 Gauss), so electron confinement is achieved without electron cyclotron resonance.

Magnetically Enhanced RIE (MERIE)



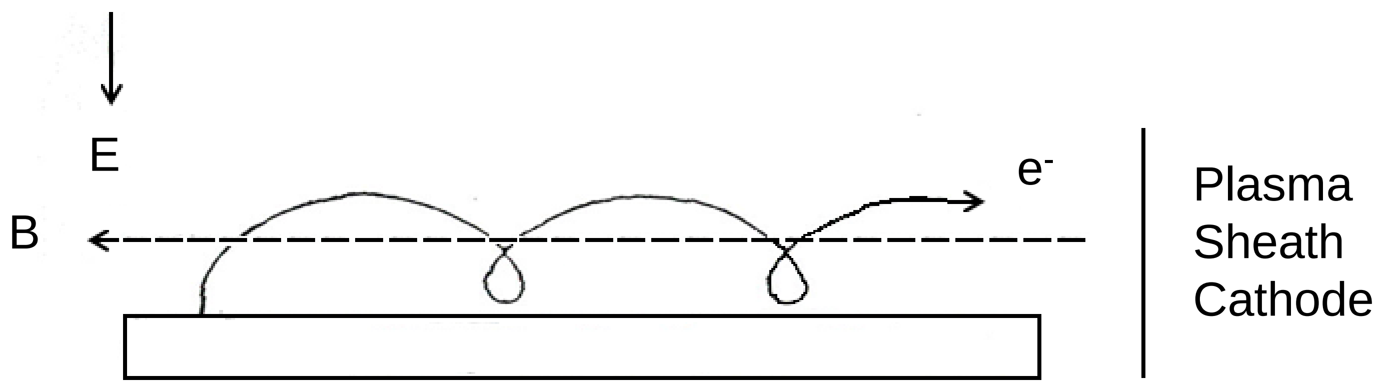
E – Electric Field Vector
B – Magnetic Flux Vector
Rotation of these vectors occurs at low frequencies

The Effect of a Magnetic Field on the Plasma

- The magnetic confinement makes plasma generation more efficient by preventing electron loss to the grounded chamber walls
- Plasma is denser, more reactive species and charged particles, thus increasing etch rates
- This configuration allows the DC bias to be reduced, leading to less energetic substrate bombardment (‘damage’)

Electron Motion in a Magnetic Field

B – Static Field
E – Field Oscillation at 13.56 MHz



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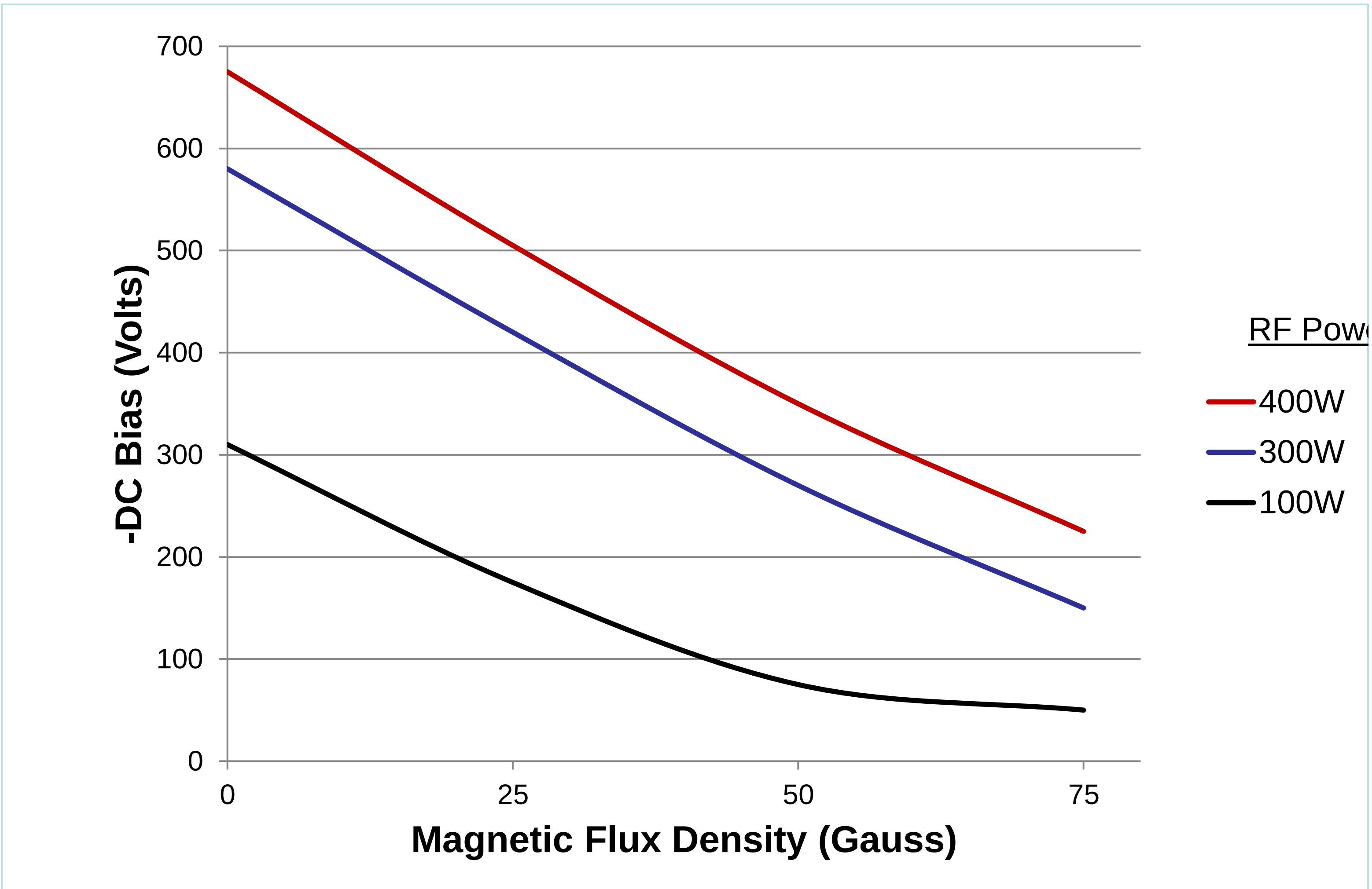
Effect of Magnetic Field on DC Bias



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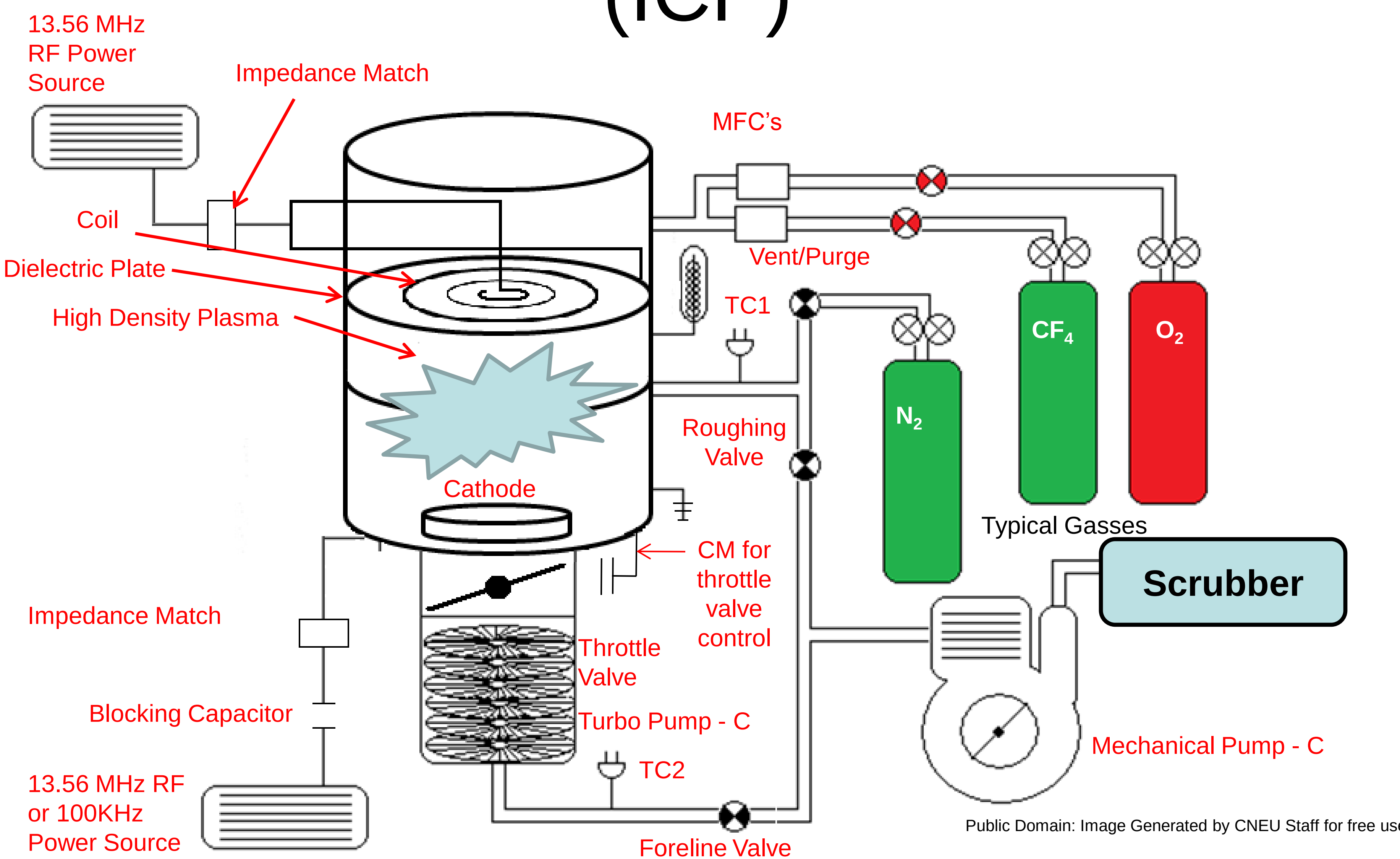
Effect of Magnetic Field on DC Bias

- More collisions = more ions
- Electrons are not lost to the walls, they are contained in the magnetic field.
- Grand result is more ion population with less individual ion energy
- Recall high individual ion energy leads to damage.
- High etch rate leads to faster throughput, and reduced manufacturing cost!

Inductively Coupled Plasma Etch (ICP)

- Inductively Coupled Plasma (ICP) reactor utilizes the electrodes driven by separate power supplies
- A sheet of dielectric material separates the electrode holding the substrate from the other electrode
- The high density plasma is confined beneath the dielectric material

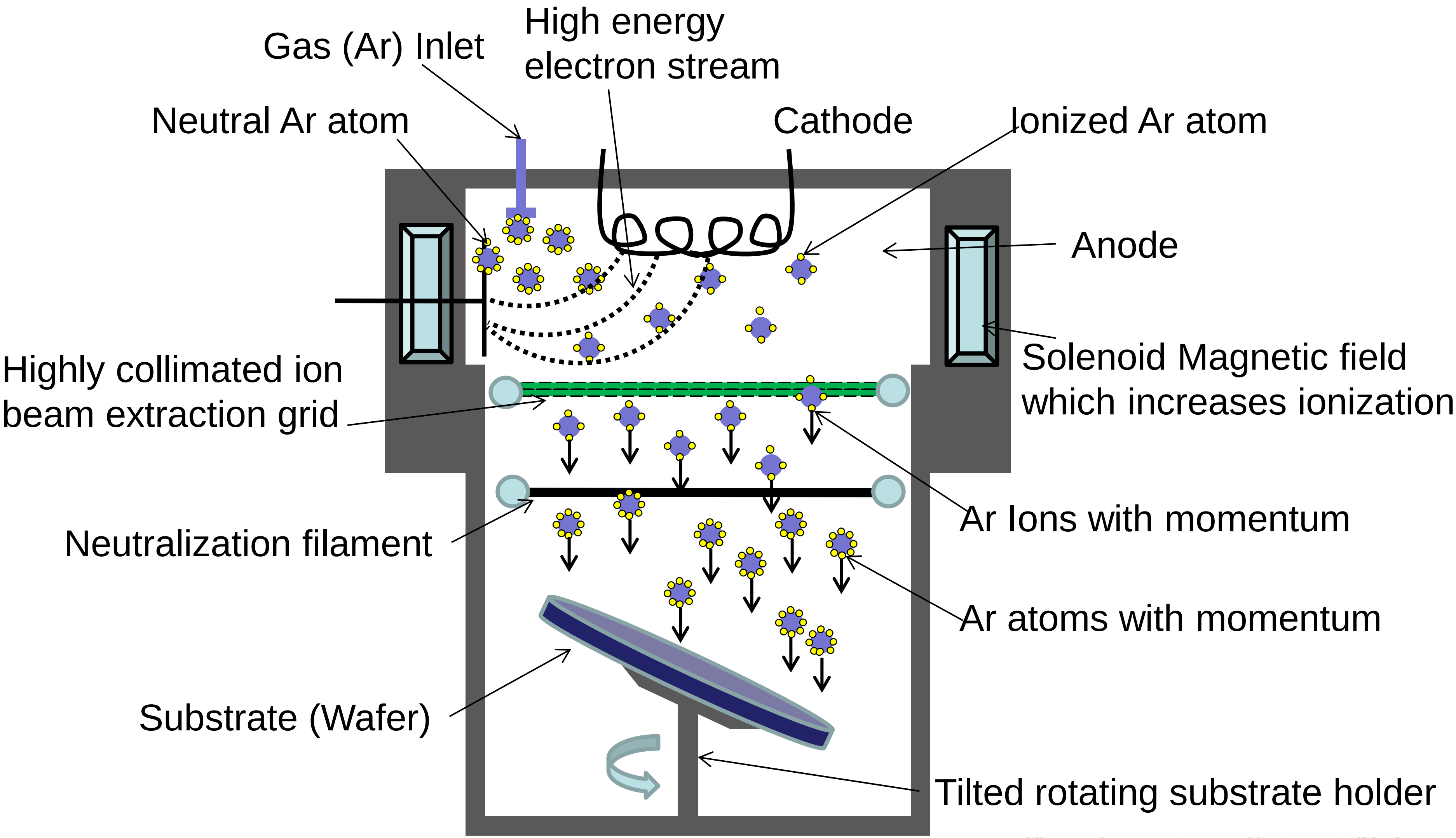
Inductively Coupled Plasma Etch (ICP)



Ion Beam Etchers (IBE)

- Use grid electrodes to focus the electrons into a culminated beam directed toward the substrate
- Substrate can be tilted with respect to the ion beam for greater control of the etch profile
- Reactors are used most often to etch hard-to-etch materials like some metals and group III-IV compounds

Ion Beam Etchers (IBE)



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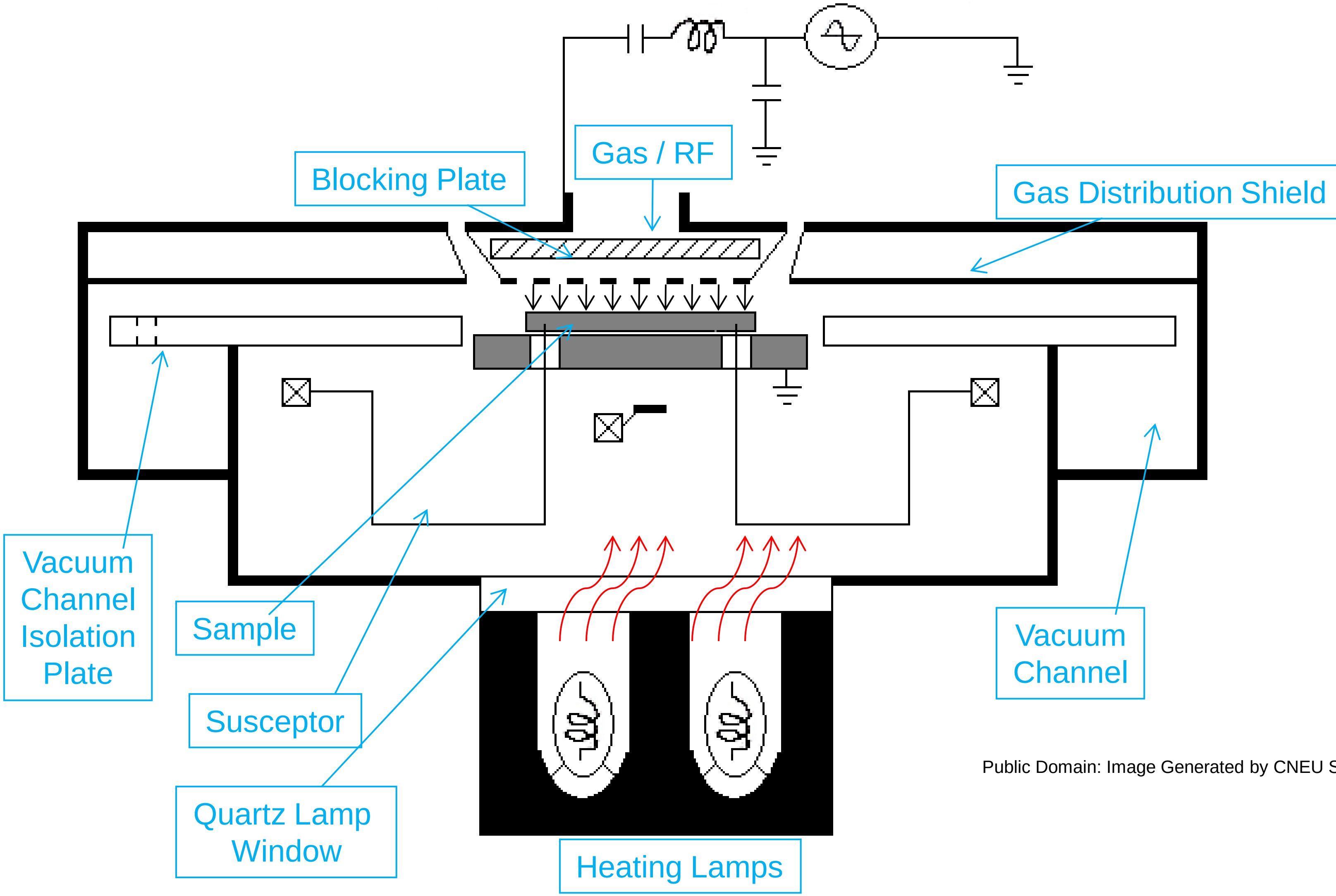
ASP Chamber
Based on design, what material, what recipe parameters?



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ASP Strip & Passivation Recipe

Recipe Parameters	**200 mm Sample**		**150 mm Sample**	
	Step 1	Step 2	Step 1	Step 2
O_2 (sccm)		3500		3000
N_2 (sccm)		200		200
H_2O (sccm)	500	300	500	300
Pressure (T)	2	2	2	2
Power (W)	800	1400	800	1400
Temperature (C)	250	250	220	220
Time (sec)	60	60	60	60

Survey of Dry Etch Equipment

Type of Etch Tool	Typical Pressure Range	Descriptions
Reactive Ion Etch (RIE)	Low (10 mT – 150 mT)	Slow etch rate, batch loading required for throughput, less affected by high rate etching damage, asymmetric electrode configuration, negative DC Bias on the cathode, no sputtering of anode, samples are placed on the powered electrode (cathode).
Parallel Plate Etcher (Planar)	Medium (100 mT – 1 T)	Usually single wafer, symmetric configuration, No DC Bias, high rate required for adequate throughout, samples can be placed either on the grounded electrode (Plasma etch Mode) or the powered electrode (Reaction Ion Etch Mode), sputtering of both electrodes can occur, less sample – to – sample variability than in a typical batch system, good individual sample endpoint detection control possible.
Downstream Microwave Etch	High (0.5 – 2 T)	No high energy ion bombardment, reactive species created outside of the etching region, then transported to the etching chamber downstream of the plasma, etching is isotropic without application of bias to the sample, useful for photoresist stripping and other “non-critical” applications.

Survey of Dry Etch Equipment

Type of Etch Tool	Typical Pressure Range	Descriptions
Hexode RIE	High 100's mT	Batch process RIE tool. Wafers are mounted on a large six-sided cathode, etch chamber walls acting as the anode. The large cathode distributes the bias, and with the high pressure results in low bombardment. Use often as a photoresist striper.
Magnetically Enhanced Reactive Ion Etch (MERIE)	Low (10 mT – 250 mT)	Magnetic field is responsible for more efficient plasma generation at lower pressures, higher ion and reactant species production, denser plasma, high etch rates, lower bias for less bombardment "damage", controlled anisotropy.
Electron Cyclotron Resonance (ECR Reactor)	Very Low (< 20 mT)	Magnetron microwave source, magnetic coils, high density plasma, low ion energy, complicated and expensive, technology continues to mature

Survey of Dry Etch Equipment

Type of Etch Tool	Typical Pressure Range	Descriptions
Inductively Coupled Plasma (ICP)	Low (100’s mT)	ICP is a high density plasma system that uses a separate power supply outside of the etch chamber to control the plasma in the etch chamber. Separate power supplies for plasma generator and sample electrode allow for better control of ion generation.
Ion Beam Etch (IBE)	Low (< 100 mT)	Physical sputter mechanism, high excitation energy, strongly directional (anisotropic), ion density and acceleration voltage can be independently controlled, poor selectivity, low etch rates.
Advanced Strip & Passivation (ASP) Also known as Resist Strip & Passivation (RSP)	High (0.5 - 2 T)	Two stage process. The first step neutralizes caustic chemicals on the sample by flowing in stem. The second stage ashes of the PR with oxygen. High pressure results in shorted mean free path and reduced bombardment.

Outline

- Introduction
- Etch Systems
- Cluster Tools

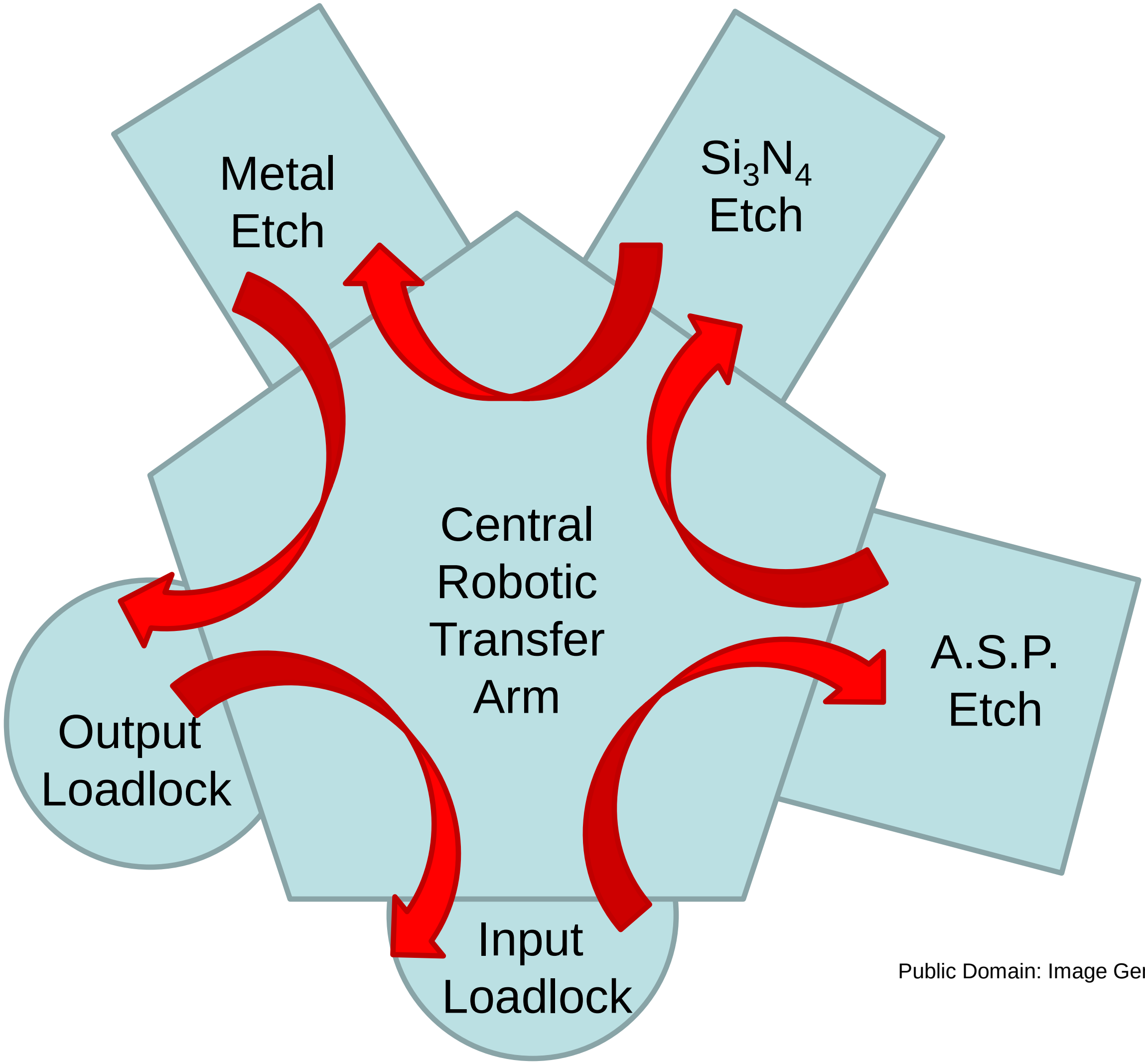
Cluster Tools

- Overall trend toward cluster tools in the field
- Once loaded into the machine, a substrate remains under vacuum until all the processes are completed
- Cluster tools decrease contamination by reducing handling and limiting exposure to the environment
- Multiple chambers performing the same etch can be used to increase production throughput. Chambers for non-etching process can also be combined with the etch process chambers.

Cluster Tool Considerations

- Decrease in cycle time (increased throughput)
- Reduced handling and exposure to contamination
- Cost reduction via sharing robotic handler, software/hardware control system, and vacuum system
- Small footprint

Generic Cluster Tool Configuration



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