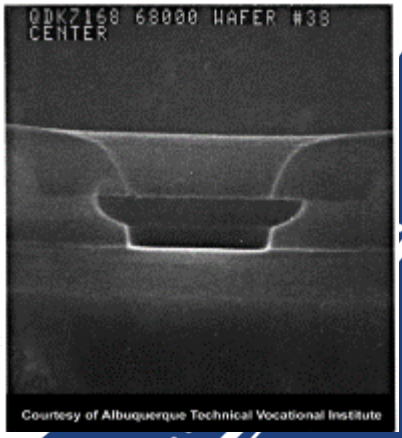
NACK CENTER
Building College-University Partnerships for Nanotechnology Workforce Development

Plasma Technology, an enabling tool for modern manufacturing

Terence Kuzma

a) Directional Etching

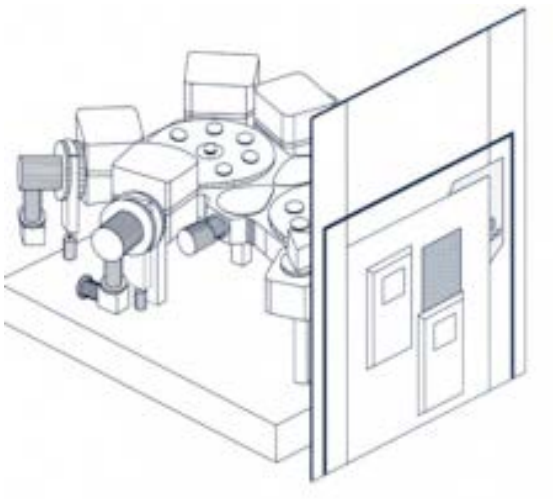
b) Isotropic Etching



PennState

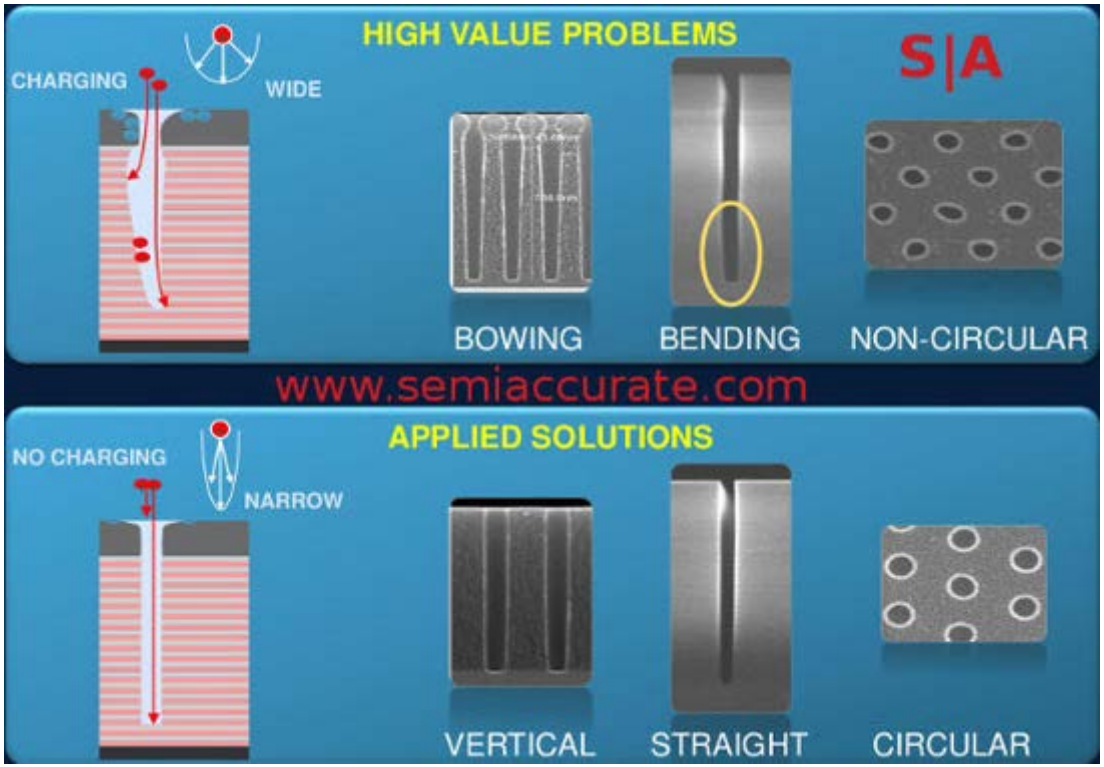
Today's Outline

- Why/what is nanomanufacturing
- Plasma technology, describing the tool
- Summary that will change your life

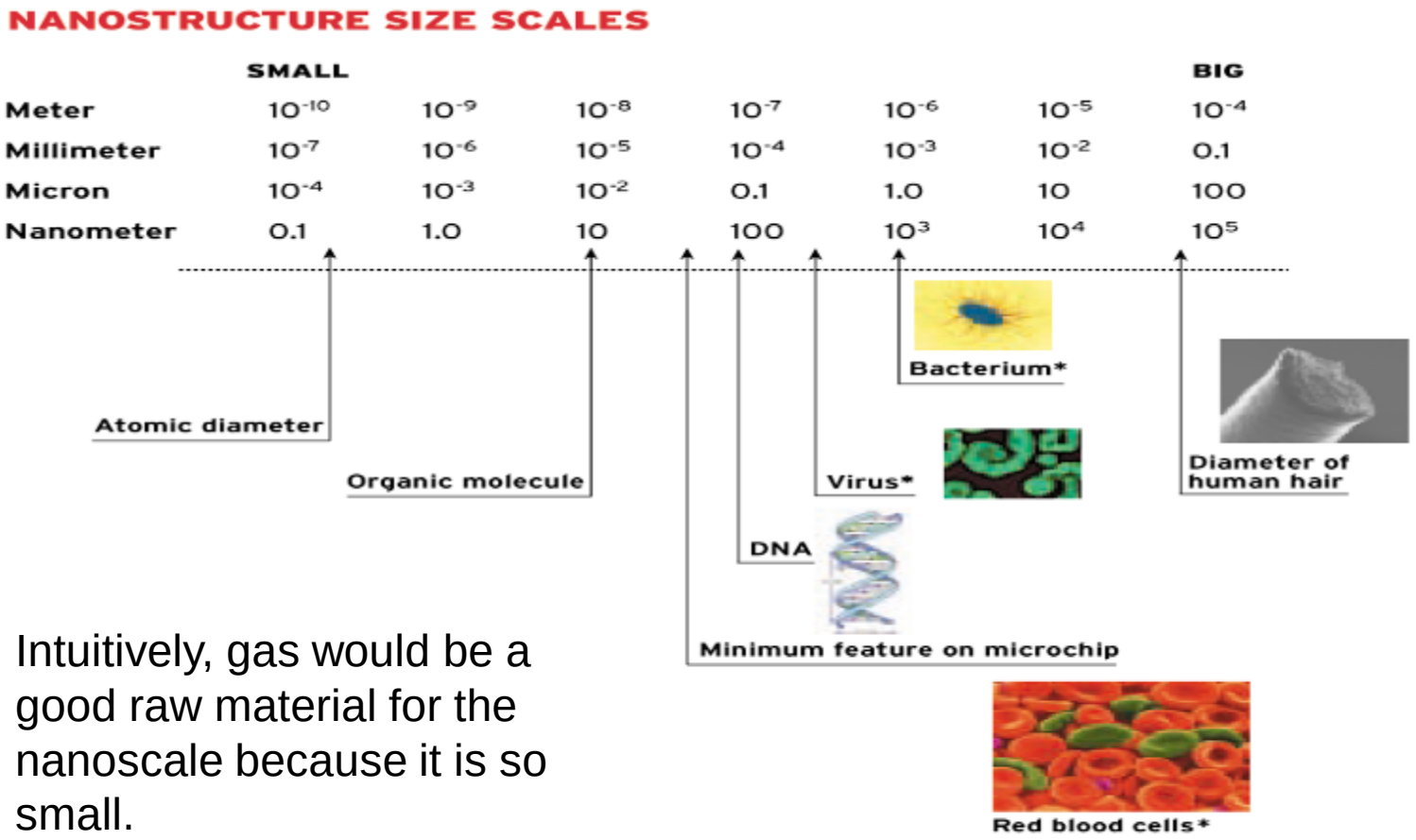


What is Nanofabrication?

- Nanomanufacturing is the process of controlling materials on the nanoscale to make products better. Generally this requires a very precise and repeatable process. Plasma technology fits these constraints.



Why nanotechnology is important



Intuitively, gas would be a good raw material for the nanoscale because it is so small.

* © Dennis Kunkel

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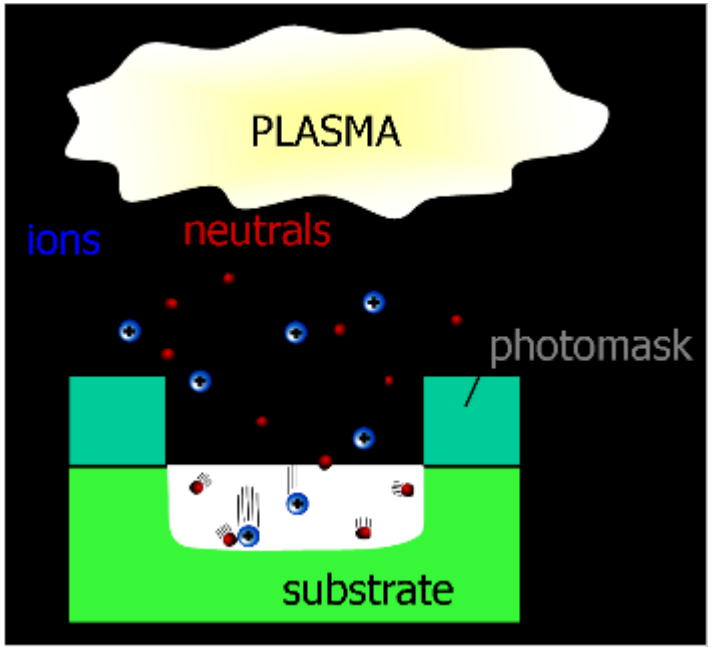


Plasma technology, describing the tool

- Plasma technology can make products better, and sometimes unique products.
  - Plasma for our discussion is electrically excited gas under a vacuum.
  - Generally plasma is “simple”, lacks uncontrolled variables.
  - Because plasma technology is controlled, it can be repeatable. This increases yield. $$$
  - Often plasma technology can be utilized in an assembly line. This makes products cheaper, and widespread.
  - It can be used to create films or particles.
  - It can be used to modify surfaces.
  - ***It can be used to remove material, and to produce patterns.***
  - No cell phones without plasma technology, no internet, no digital for the masses.

Etch technology, describing the tool

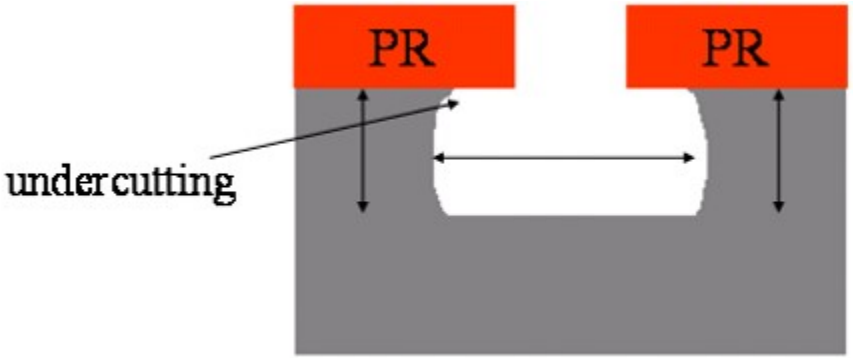
- This presentation will focus on etching, selective material removal to pattern a surface.
- Electrically excited gas is a plasma, and it has two major energy factors to accomplish manufacturing: chemical energy (C) and kinetic energy (B). These two forms of energy act synergistically. C*B
- We can “chisel out” features as big as a virus
- Two basic types of etch profiles
  - 1. Wet Etch – Just like an “acid”
  - 2. Dry Etch – “Like crafty sand blasting”, this is our topic but we will contrast wet etch first and see why it is really not “nano”.

Etch technology, describing the tool

- Etch = Selective removal of material… Can be liquid or gas byproduct
- Two basic types of etch profiles. Divide/conquer
  - Isotropic = Bowed sidewalls, where the lateral etch rate matches the vertical rate. (Wet, or plasma)
  - Anisotropic = Relatively straight sidewalls, where the vertical etch can exceed the lateral etch rate. (Plasma only)

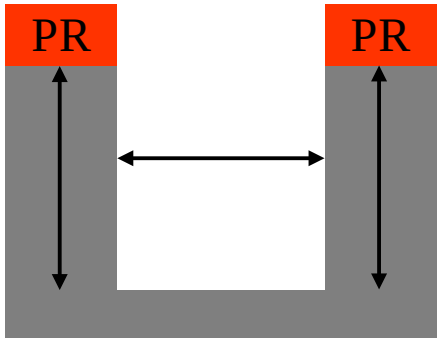
Isotropic Vs Anisotropic

- Isotropic
  - Characteristic wet etch profile, “energy” is equal in all directions, directed at depth and width.
  - Wet chemistries tend to undercut, producing this profile.



Anisotropic Vs Isotropic

- Anisotropic
  - Characteristic dry (plasma) etch profile, a function of pressure and sidewallpassivation
  - Energy greater in depth than width!



Etch Profiles

- Wet Chemical Etching: isotropic
  - *Undercut profile, increased real estate used, loss of dimensional control*

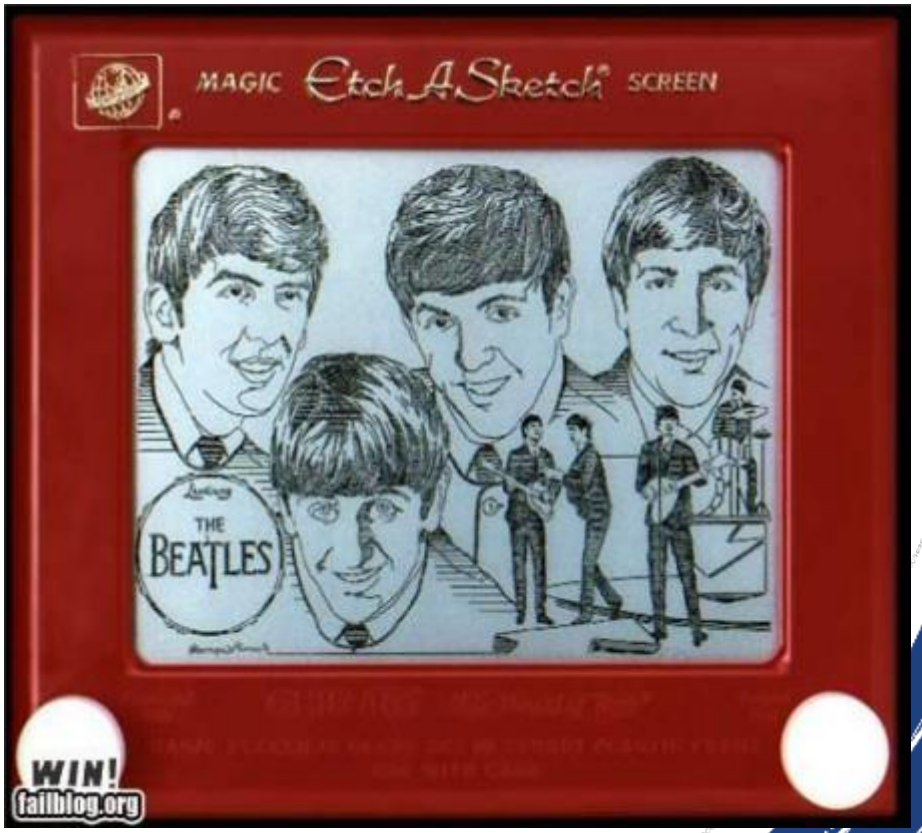
- Plasma Etching: anisotropic or directional
  - *vertical sidewalls*

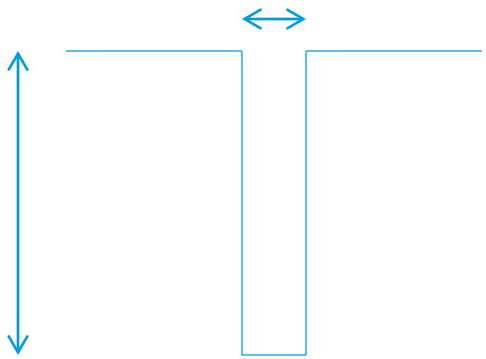
Wet Etch (isotropic)

- Positive Characteristics
  - Generically, dipping a masked substrate in an “acid”. Chemistry does the work.
  - Low cost
  - Well understood
  - Possible to do many substrates at once
- Negative Characteristics
  - Only isotropic profiles – limited application
  - Large amounts of waste
  - Solutions change, lacks control, repeatability
  - Temperature dependent
  - Not for smaller features, due to surface tension (usually less than 3 microns)
  - Not that interesting for PowerPoint……., but it shows we need plasma etching in the gas state.

Bonus Poll, The Beatles

- 1962 the drummer _ _ _ _ _ _ joins the Fab 4.
- There are two knobs on this etch-a-sketch
  - Left and right C
  - Up and down B
- Energy vectors
  - Chemical (L/R) – chem reactions
  - Bombardment (U/D) – ions
  - "Kinda" for simplicity – first order





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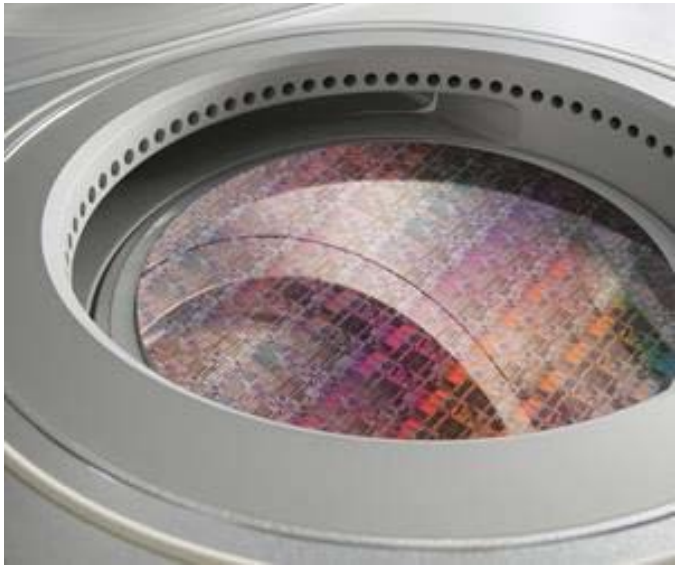


Plasma Overview

- Fourth state of matter
- A good example of a “plasma system” that you are familiar with is the fluorescent lights in this room.
- What do you know about the fluorescent lights?
  - Under vacuum
  - Used electrical bias
  - Different colors, white, pink, blue.

Plasma technology, describing the tool

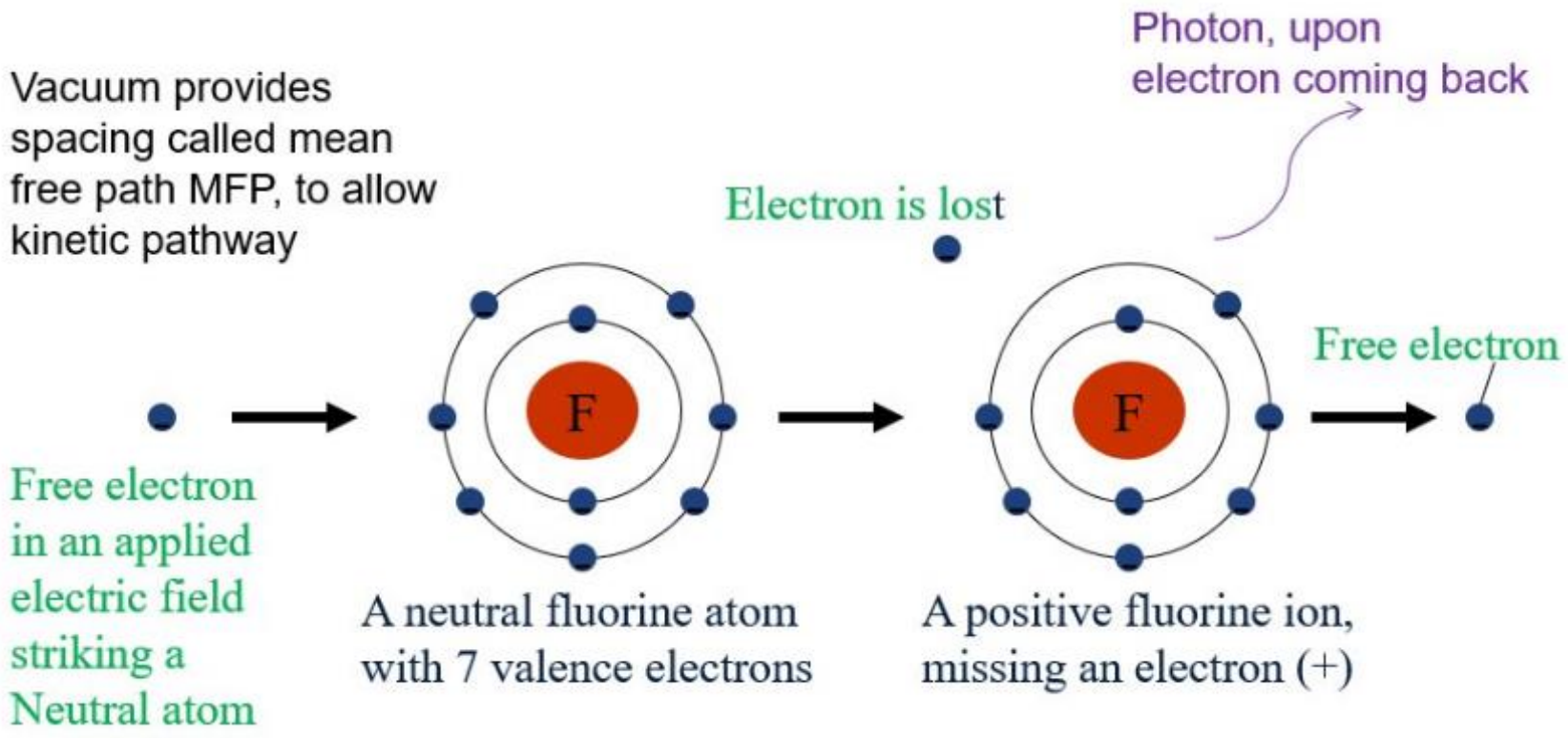
Plasma Overview

- Vacuum = clean, new gas in, used gas out
  - Well controlled purity 99.9997% fresh gas
  - Gas glows a specific color – remember orbital excitation – quantum effects.
  - In this man made environment, unique chemical reactions can be repeatable.
  - Ionization is primarily controlled through the spacing of the atoms in the vacuum chamber. Collisions cause electron disassociation.

Plasma Overview

- A dry plasma etch contains:
  - Radical that chemically react with the wafer and **selectively** remove material
  - Ions that remove material through **physical bombardment** (no selectivity) and alter uniformity
  - Neutrals
  - Electrons aid in sustaining the plasma
  - These different “energies” can modify a surface
    - Again, etch, deposition, and surface modification

Gas plasmas are a function of ionization



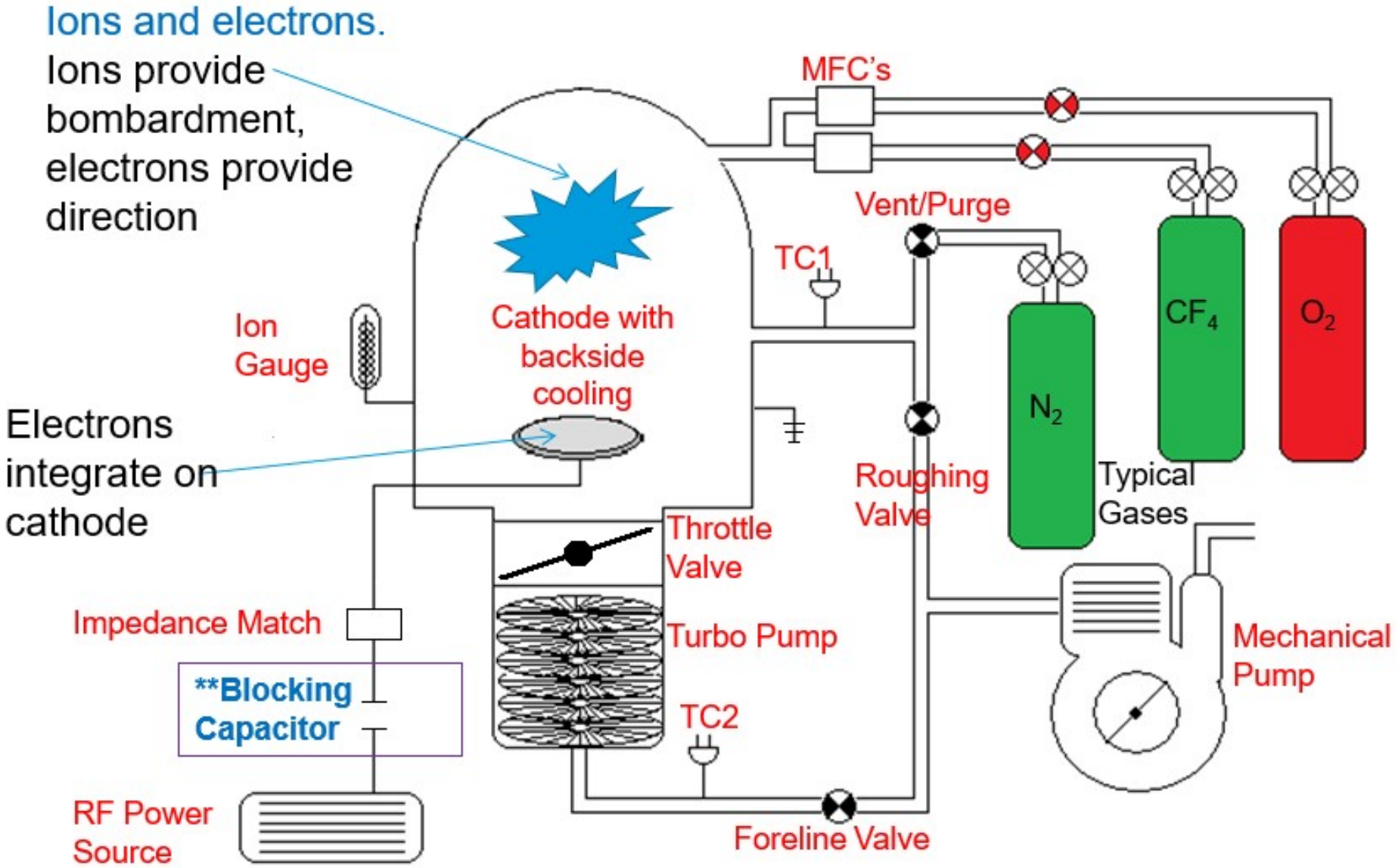
Plasma technology, describing the tool

- Q. Why is this important?
- A. To provide KE and Chemical activity at the surface. KE=B, and Chemistry=C
- C*B = unique energy, custom width verses depth for unique profiles

A Plasm Etch System

- Drawing a typical system to integrate concepts listed below:
  - Ions want to gain negative charge to become neutral.
  - We can capture electrons by isolating an area with a CAPACITOR. Electrons = negative DC.
  - Pressure controls *mean free path*
  - The RF electrical power is connected to the cathode through a capacitor. This provides AC power and blocks the DC electrons from bleeding away.

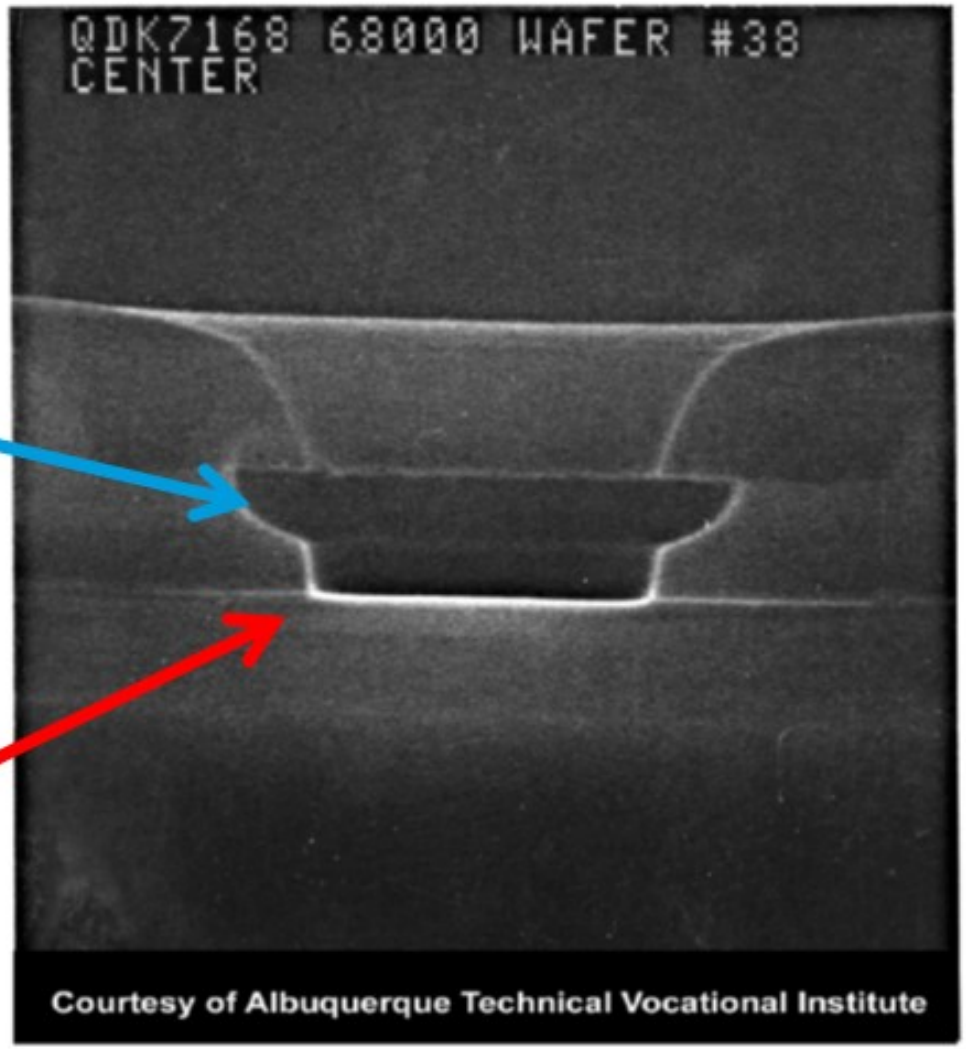
Reactive Ion Etch



The "Wine Glass" Etch Profile

Pressure increased, isotropic

Pressure reduced, anisotropic



Courtesy of Albuquerque Technical Vocational Institute

Gives us the ability to repeatable create 3D geometries as big as a virus!

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Summary (life changing)

- Nanofabrication is valuable. $$$
- One enabling nanofabrication tool is plasma etch.
- Plasmas are necessary for some portion of the nanofabrication market.
- Understanding, and integrating core engineering principles is powerful.